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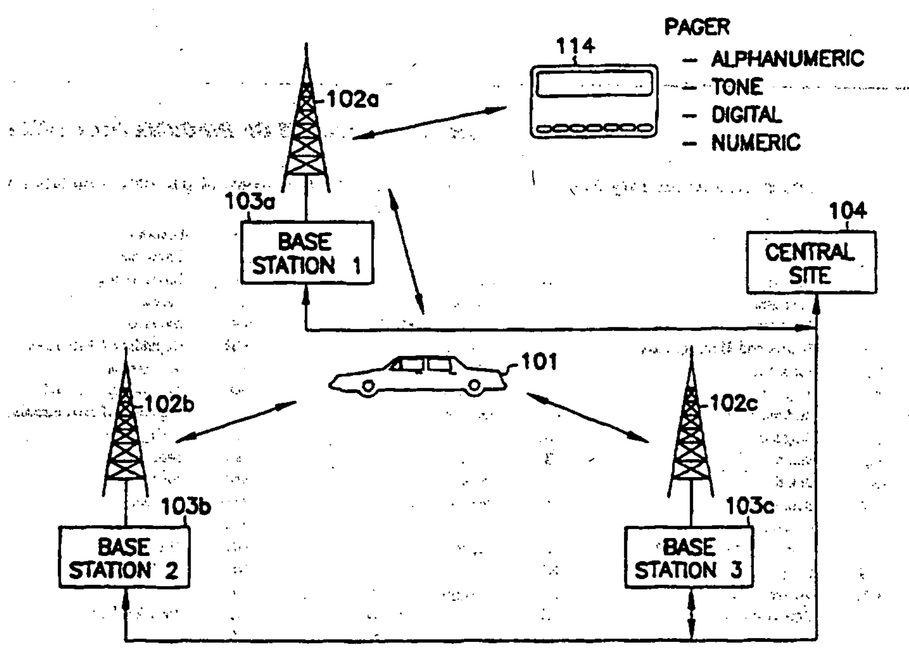
(57) Abstract



An automated theft alarm system integrated into a vehicle for use with a two-way paging system and a vehicle location system is described. The possible theft or break-in of a vehicle is detected by a system integrated within the vehicle which then transmits a two-way paging signal to a two-way paging base station. The base station then transmits an alert to the vehicle owner using an existing paging infrastructure and the vehicle owner is then given the opportunity to determine if an actual theft or break-in is underway. If an actual emergency situation exists, the vehicle owner uses the two-way paging device to transmit an actual theft alarm to an authority such as the police which also can automatically invoke a vehicle location system at the two-way paging base stations. The network of two-way paging base stations then use interferometric direction finding and triangulation on the two-way paging back link signal to locate the vehicle. The vehicle is instructed to continuously transmit signals which allow the two-way paging system to accurately monitor the location of the stolen vehicle. The two-way paging back link signal is in the form of a low power, frequency hopped spread spectrum signal. The system may also be used to remotely monitor the condition of the vehicle and remotely control selected functions within a vehicle.

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VEHICLE ALARM AND LOCATION SYSTEM

Field of the Invention

The present invention relates to monitoring and location systems and in particular to an owner-directed monitoring, theft alarm and vehicle location system to remotely monitor vehicles, minimize false alarms and locate stolen vehicles.

Background of the Invention

A variety of theft alarms are used for vehicles to alert the public and the owner of the vehicle of a potential theft or break-in. Most common systems use local alarms in which an audible alarm is sounded sometimes in connection with a visual display such as flashing lights. The theft detection or break-in detection system are typically activated by an attempted break-in or an attempted theft of the vehicle.

Remote alert devices which may alert the police or an owner of a vehicle that a possible theft is underway is also known in the art. For example, U.S. Patent No. 5,081,667 to Drori et al. uses the vehicle cellular telephone to call a pager to alert the vehicle owner of a possible theft. The vehicle telephone can also transmit location information such as coordinates to alert the owner of its location.

Special purpose two-way communication systems have also been used with vehicle alarms to alert the owner that a possible break-in or theft is underway. For example, U.S. Patent No. 4,821,309 to Namekawa describes a communication device having a transmit and receive capability. This communication device is a special purpose device under the design of the Nambucca patent but is not part of any standard paging infrastructure. Likewise, U.S. Patent No. 4,940,964 to Dao uses a two-way communication system which requires the use of a special two-way communication device. These systems are all subject to false alarms.

Vehicle location devices are also known in the art. One type of vehicle location system is where the vehicle determines its own location and transmits its location information to a remote site such as that described above in

conjunction with U.S. Patent No. 5,081,667 to Drori et al. Other types of vehicle location systems require the monitoring of transmitted signals from the vehicle such as that found in U.S. Patent No. 4,728,959 to Maloney et al. in which cellular signals can be monitored from a vehicle to determine a vehicle location. The Maloney et al. patent is not described for use in conjunction with any theft detection system.

There is a need in the art, therefore, for a theft alarm system which minimizes the amount of false alarms by first alerting the owner of the vehicle using a two-way paging system based on an existing paging infrastructure. There is also a further need in the art to minimize false alarms by allowing a vehicle owner to determine if an actual theft or a false alarm is underway. There is a further need in the art for a remote monitoring capability to determine the status of a vehicle and control selected functions within a vehicle from remote locations. There is a further need in the art for an integrated system which can do vehicle location based upon the invocation of a search by the vehicle owner.

Summary of the Invention

The present invention solves the aforementioned shortcomings in the art and other problems which will be understood by those skilled in the art upon reading and understanding the following specification. The present invention is directed to an automated theft alarm system integrated into a vehicle for use with a paging system. The possible theft or break-in of a vehicle is detected by an integrated system within the vehicle which then transmits a communication signal to a paging central station. The central station then transmits an alert to the vehicle owner using an existing paging infrastructure and the vehicle owner is then given the opportunity to determine if an actual theft or break-in is underway. If an actual emergency situation exists, the vehicle owner sends a message to the paging central station to transmit an actual theft alarm to an authority such as the police. In one preferred embodiment, the vehicle sends the alarm alert signal using the back link of a two-way paging system. In another preferred embodiment, the vehicle owner sends the alarm

message to the paging central station using the back link of a two-way paging system. In yet another preferred embodiment, the vehicle owner sends the alarm message to the paging central station using a cellular or land-based telephone.

Upon receipt of an alarm message from the vehicle owner, the paging central station will invoke a vehicle location system to locate the vehicle. In one preferred embodiment, the central paging station uses interferometric direction finding and triangulation on the signal from the vehicle to locate the vehicle. The vehicle is instructed to continuously transmit signals which allow the system to accurately monitor the location of the stolen vehicle. In the preferred embodiment of the present invention, the two-way paging back link signal is in the form of a low power, frequency hopped spread spectrum signal. In alternative embodiments, differential time of arrival or dead reckoning location systems may be used to locate the vehicle. Dead reckoning, or portable locating device, is a well-known system where the transmissions from the vehicle are known and the portable locating device is searching for the transmission by using two antennas based on the ratio of the magnitude of the received signal strength. If the sinal strength on the two antennas are the same, the transmitter is straight ahead. If the right antenna receives a stronger signal, the transmitter is to the right, etc.

In yet another alternate embodiment, the present invention may be used to remotely monitor the condition of the vehicle, remotely control selected functions within a vehicle, or update the vehicle on its present location.

Description of the Drawings

In the drawings, where like numerals describe like components throughout the several views,

Figure 1 is a block diagram of the present vehicle alarm alert and location system;

Figure 2 is a block diagram describing the two-way paging communication network and the overall method of operating the present invention;

Figure 3 describes the communications equipment placed in the vehicle;

Figure 4 is an overview of the infrastructure of the multi-path resistant frequency-hopped spread spectrum mobile location system;

Figures 5, 5a and 5b describe the synchronization and message format of the outgoing paging signals from the base stations;

Figure 6 describes the format of the frequency-hopped spread spectrum signal transmitted by the remote mobile units;

Figure 7 is a diagram of the receiving antennas of the base stations including a plurality of dipole antennas and a single reference omni antenna;

Figure 8 is a three antenna array for an interferometric direction finding system;

Figure 9 is an ambiguity plane plot of the three antenna array of Figure 8;

Figure 10 is the ambiguity plane for the ratios 5:6 of $\lambda/2$ the three antenna array of Figure 8;

Figure 11 is an example of multi-path reflections in an urban environment;

Figure 12 is diagram showing triangulation of the location of a remote mobile unit between three base stations; and

Figure 13 is a diagram of a gnomonic plot of the measured bearings of the direction finding algorithm on a sphere.

Detailed Description of the Preferred Embodiment

In the following detailed description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific preferred embodiments in which the inventions may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the spirit and

scope of the present inventions. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present inventions is defined only by the appended claims.

System Overview

Referring to Figure 1, vehicle 101 is equipped with an alarm system which detects such things as unauthorized entry, possible theft, unauthorized use, etc. For example, upon detection of a possible theft of the vehicle 101, an alarm condition is invoked which may include an audible and/or visual indication of the alarm condition. In the alternative, a silent alarm condition may occur in which there is no local indication of trouble. Such alarm systems are well known in the art and do not require elaborate description.

The possible theft or break-in of the vehicle 101 is detected by the alarm system within the vehicle which sends an alarm signal to a transmitter/receiver within vehicle 101. In the preferred embodiment, the transmitter/receiver is a two-way paging device using any one of a number of two-way paging formats. The two-way pager then transmits an alarm message on a two-way paging signal to a plurality of transmit/receive antenna towers 102a, 102b, 102c, connected to two-way paging base stations 103a, 103b, 103c, respectively. In the preferred embodiment, the two-way paging system may be a system in which the communication link from the base stations 103a, 103b, 103c, to the vehicle 101 is a standard paging signal (downlink) and the communications link from the vehicle 101 to the base stations 103a, 103b, 103c, may be, by way of example and not by way of limitation, a low power frequency hopped spread spectrum signal (uplink) such as the type described in U.S. Patent Number 5,335,246 entitled "LOW-POWER FREQUENCY-HOPPED SPREAD SPECTRUM ACKNOWLEDGMENT PAGING SYSTEM", issued July 4, 1995, which is assigned to the same assignee of the present invention.

Upon receipt of an alarm message on the two-way paging uplink, the plurality of base stations 103a, 103b, 103c forward the alarm message to a central station 104. The alarm message is then forwarded to a specific pager address by the central station 104 using the paging signal downlink in an existing

paging infrastructure via antenna towers 102a, 102b, 102c. The alarm message is received by a remote mobile paging device 114 carried by the vehicle owner who is then given the opportunity to determine if an actual theft or break-in is underway. In the preferred embodiment, the remote mobile paging device 114 is a two-way paging device using any one of a number of two-way paging formats. In the preferred implementation of the present invention, the two-way paging system uses a low power frequency hopped spread spectrum uplink signal such as the type described in aforementioned U.S. Patent Number 5,335,246.

If an actual emergency situation exists, the vehicle owner sends an actual theft alarm message to an authority such as the police. The method of sending the actual theft alarm message may be by telephone, if the vehicle owner is equipped only with a one-way paging device, or it may be via the two-way paging device 114 such as the type described above. In one embodiment, the vehicle owner may also remotely disable vehicle 101 or sound an alarm on vehicle 101 by sending a disable message to the vehicle using the remote mobile two-way paging device 114. Vehicle 101 is equipped with a remote mobile two-way paging device which has a similar transmitter and receiver as the remote mobile two-way paging device 114 which can communicate with the vehicle owner, a monitoring authority, or the like.

If the vehicle owner authorizes an actual alarm condition, the plurality of two-way paging base stations then use a direction finding technique to locate the vehicle using the signal transmitted by the vehicle as the homing signal. Such types of vehicle location which may be used are interferometric direction finding, differential ranging, dead reckoning portable locating device or differential time of arrival.

In the preferred embodiment of the present invention, interferometric direction finding on the two-way paging back link signal is used to locate the vehicle in relation to each base station. The antenna towers 102a, 102b, 102c, of the base stations 103a, 103b, 103c, respectively, are each equipped with an array of irregularly spaced receiving antennas which measure

the phase differences on the incoming uplink signal from the remote mobile two-way paging device within vehicle 101 to determine the angle of arrival of the signal in relation to the base station. The vehicle is instructed to continuously transmit uplink signals. The base stations report the direction of arrival information to the central station 104 which then uses triangulation to locate and monitor the travel path of the vehicle 101. Such an interferometric direction finding technique is described in U. S. Patent Application Serial Number 08/329,523 entitled "MULTIPATH-RESISTANT FREQUENCY-HOPPED SPREAD SPECTRUM MOBILE LOCATION SYSTEM" filed September 26, 1994, which is assigned to the same assignee as the present patent application.

In the alternative, another interferometric direction finding technique which may be used to locate the vehicle, if some other type of signal other that frequency-hopping spread spectrum is transmitted by the vehicle, is described in U. S. Patent Application Serial Number 08/329,549 entitled "DIRECTION FINDING AND MOBILE LOCATION SYSTEM FOR SPECIAL MOBILE RADIO SYSTEMS" filed September 26, 1994, which is also assigned to the same assignee as the present patent application. Yet another direction finding technique, differential ranging, is described in U. S. Patent Application Serial Number 08/389,263 entitled "DIFFERENTIAL RANGING FOR A FREQUENCY HOPPED REMOTE POSITION DETERMINATION SYSTEM" filed February 16, 1995, which is also assigned to the same assignee as the present patent application.

In an alternate embodiment, the present invention may be used to remotely monitor the condition of the vehicle and remotely control selected functions within a vehicle. For example, vehicle 101 may send messages to pager 114 such as the internal temperature of the vehicle or the like. Or, if pager 114 is a two-way pager, it may operate as a smart remote control by controlling certain functions with the vehicle such as starting the vehicle, turning on heat or air conditioning, lights, remotely arming the alarm system, etc. The message format used in communicating between the vehicle 101 and the pager 114 may be the type described in U. S. Patent Application Serial Number 08/528,246

entitled "TWO-WAY PAGER HAVING PRE-RECORDED UPLINK MESSAGES AND PAGER TO PAGER MESSAGING" filed September 14, 1995, which is also assigned to the same assignee as the present patent application.

System Operation

Figure 2 describes a preferred two-way paging communication network and the overall method of operating the present invention. The two-way paging communication system within vehicle 101 is in communication with the two-way paging network comprising paging transmission and reception towers and the central operation station or central station. The communication system is also linked to a public telephone network 106 to communicate with remote telephones, computers, fax machines and the like. The central station may also be linked to other communications networks such as the Internet, satellite communications networks, etc.

The vehicle owner 105 can communicate with vehicle 101 via two-way pager 114 to obtain status of the vehicle such as whether the alarm is armed, the internal temperature of the vehicle, whether the lights are on, etc. The vehicle owner 105 can also send commands to vehicle 101 to enable certain functions such as to arm the alarm system, to start the vehicle, to turn on the heat or air conditioning, to turn on or off the lights, etc.

Vehicle 101 can communicate with the vehicle owner via two-way pager 114 to alert the owner of an alarm condition such as the unauthorized entry or theft of the vehicle. The vehicle owner 105 can determine if the alarm message is a false alarm, since the vast majority of car alarms are false alarms. By allowing the vehicle owner to determine the status of the vehicle alarm, most if not all false alarms are avoided. In the case of a false alarm, the vehicle owner can remotely reset the alarm, or physically check the vehicle first.

In the case of a real alarm, the vehicle owner 105 can authorize the police or some other authority to begin to search for vehicle 101 using, for example, the two-way paging communications network, or by some other communications means such as a cellular or land based telephone. The two-way

paging signals emanating from the vehicle are monitored at the base stations the angle of their arrival is calculated using interferometric direction finding. The direction information is then collected at the central station where triangulation of the angle information is used to obtain an accurate location of the vehicle. The two-way paging communication equipment within the vehicle is instructed to continuously or periodically transmit so that the location of the vehicle constantly monitored and updated. A chase car 107 can also communicate with the two-way paging system to receive updated information of the location of the stolen vehicle.

In-Vehicle Components

The vehicle 101 is equipped with a two-way paging system as described more fully below. Referring to Figure 3, the two-way communication system includes an antenna 108 which preferably is manufactured with a low profile so it can be hidden on or within the vehicle such as under the roof line or built into the trunk lid. The two-way paging and control device 109 is constructed having essentially the same capabilities as a two-way pager 114. In addition, the control functions of the device 109 may include an integral location system which could display the current location of the vehicle as determined by and downloaded from the two-way paging communications network described in conjunction with Figure 2. The two-way paging and control device 109 may be accessible to the vehicle driver, or it may be hidden from view to mask the fact that the car contains a silent alarm and location system. Hiding the two-way paging and control device 109 may be necessary to prevent a thief from disabling the device.

The two-way paging and control device 109 may also have an interface to a two-way pager 114 via an RS232 link, or the like. In this embodiment, the two-way paging and control device 109 in vehicle 101 and the vehicle owner's two-way paging the device 114 may have the same cap-code, or address, to simplify operation and identification. The vehicle owner's two-way pager 114 is then detachable from the two-way paging and control device 109 for portable operation.

The two-way paging and control device 109 includes an interface to the vehicle alarm indicators to receive status from the vehicle (such as an unauthorized entry), or to control certain operations.

Two Way Paging Communications Network

In the preferred embodiment of the present invention, the two-way paging communications devices and the base stations of the present invention are as described in the aforementioned U.S. Patent Number 5,335,246 entitled "LOW-POWER FREQUENCY-HOPPED SPREAD SPECTRUM ACKNOWLEDGMENT PAGING SYSTEM", issued July 4, 1995. The communication infrastructure of this two-way paging system serves as part of the basis of the present invention and the reverse pagers of this acknowledgment pager system operate identically to the two-way pagers in the present system. The present invention allows the accurate location of the two-way pagers whether while moving with the vehicle 101 or while stationary with the user 105. The accurate location is ensured even in noisy and multi-path environments such as those found in urban environments and irregular terrain environments.

Figure 4 depicts the major components of the two-way paging communication system. The two-way paging terminal 110 at the central site operates to provide synchronization and messaging information through a standard paging terminal 116 to the two-way paging communications devices 114 (also known as remote mobile units 114) via direct links to the base stations BS_1, BS_2 and BS_3 through ground based radio links (not shown) or through a satellite uplink/downlink using a geostationary satellite (not shown). The base stations BS_1, BS_2 and BS_3 include transmit and receive towers 113a, 113b and 113c, respectively and base station terminals 201a, 201b and 201c, respectively. Terminals 201a-201c are required for producing the accurate synchronization information needed to be transmitted to the two-way paging communications devices 114 and for local processing of the received messages for direction finding. This synchronization information is used to coordinate the response of messaging from the plurality two-way paging communications devices 114 so as to minimize collisions within groups of two-way paging communications

devices and eliminate collisions between groups of two-way paging communications devices.

Base Station to Pager Synchronization

Standard paging messages sent from the base stations BS_1, BS_2 and BS_3 to the plurality of two-way paging communications devices 114 are, in the preferred embodiment, sent as digital data encoded in the POCSAG paging standard. These messages may be used to interrogate the two-way paging communications devices 114 to activate the two-way paging communications device to allow the base stations to begin the location process. Typically the paging channel has a center frequency of 143.160 MHz, with an NRZ FSK data rate of 512 bps or 1200 bps. Other bit rates such as 2400 baud (bps) are also feasible.

Figures 5a and 5b (viewed together as Figure 5) describe the POCSAG paging communications protocol as modified for use by the preferred embodiments of the present invention. In the top line of Figure 5a, a greatly compressed time line of digital data transmitted according to the POCSAG protocol is shown. Batches of messages are transmitted in groups as shown in the details in the subsequent lines below the top line of Figure 5a. In the second line of Figure 5a, a 1.0625 second interval (for 512 baud) is shown in which 544 bits are transmitted as a single batch. The batch is preceded by a synchronization code word SC as shown in the first line of Figure 5b. This synchronization code word is used to get the attention of two-way paging communications devices 114 in the geographic locale serviced by the paging terminal.

The synchronization code word within each batch is followed by eight frames of digital data. Each frame is divided into two portions, an address portion and a message portion. The address code word of the message of frame two of Figure 5a is shown in line two of Figure 5b while the message code word of the second half of frame two is shown in line three of Figure 5b. The address code word is preceded by a digital zero followed by 18 address bits, two function bits and 10 check bits. The address code word is followed by an even parity bit. The message code word portion of the frame is preceded by a digital one

followed by 20 message bits which are followed by 10 check bits and a single even parity bit. Thus each frame is comprised of 64 bits divided into two 32 bit sections.

Synchronization of the base stations 103a, 103b, 103c, and the two-way paging communications devices 114 is necessary to ensure that the units 114 are transmitting at the same time that the base stations 103a, 103b, 103c, are listening. Synchronization is also necessary to coordinate the division of the large number of two-way paging communications devices 114 into groups so that members of one group use different frequency hopping patterns from members of other groups. Synchronization of the two-way pager communication devices 114 is accomplished by inserting a special frame into the POCSAG data which is used to synchronize the units.

Synchronization between the two-way paging base stations 103a, 103b, 103c and the two-way pager communication devices 114 is important on two levels. Synchronization of the two-way paging communications devices 114 within groups of two-way paging communications devices determine where along the pseudo random noise code the frequency hops are to be followed. For example, within a single group of two-way paging communications devices, all of the two-way paging communications devices within that group will be synchronized to begin transmitting at the same location in the pseudo random noise code list for any acknowledgement which may be required. Synchronization information is sent from the two-way paging terminal periodically to the addresses of each of the two-way paging communications devices within each group to remind the two-way pager communication devices 114 where along the pseudo random noise code they should be tracking. This also enables the dynamic changing of a two-way pager communication devices group membership such that if one group is experiencing a large number of collisions due to simultaneous transmissions, the two-way paging terminal 110 may re-allocate some of the two-way pager communication devices within that group to new groups to minimize collisions.

Another form of synchronization is required to synchronize the two-way pager communication devices to the exact times for transmitting frequencies from within any of the hops. This fine synchronization information, described more fully below, is transmitted as part of the POCSAG codes.

Referring once again to Figure 5a and 5b, eight frames of information are transmitted in each burst using the POCSAG format. Two-way pager communication devices 114 may be assigned to a specific frame within the transmission so that the two-way pager communication devices, once recognizing the synchronization code word, can scan a specific frame for that two-way pager's address. Once the address is found, the two-way pager can determine any group changes that may be required to re-allocate that two-way pager to a different group. In addition, the POCSAG format is used to transmit a fine time synchronization code. The fine synchronization code is a transmission of a time pulse at an exact time synchronized to a GPS (Global Positioning System) clock, or some other highly accurate time source, to synchronize all the two-way pager communication devices 114 for time of transmission.

For example, periodically during the day the two-way paging terminal 110 will send a synchronization code within the POCSAG code word to the paging terminal which is transmitted at a very precise time. In order to ensure that a precise time pulse is sent, the two-way paging terminal 110 receives accurate time information using a GPS antenna to receive accurate time of day information. The time used to send the synchronization pulse is when the day clock reaches exactly some multiple of 0.9 seconds in the preferred embodiment. In this synchronization information, 20 bits of information are transmitted to give the accurate time of day information.

In each of the two-way pager communication devices 114, the microprocessor compares this accurate time pulse which will indicate the exact time of day and compare it to its own day clock. The clock within each microprocessor is accurate down to a few milliseconds, but the time at which the synchronization pulse occurs should have a resolution much finer than that such as down to 0.1 milliseconds for time of day. In this fashion, each of the

microprocessors in each of the remote two-way paging devices can periodically realign its day clock to know within a millisecond the exact time. Each microprocessor does not actually realign its clock but changes a clock offset within memory so that it understands how far off its own internal clock is and can make the adjustment when using that clock to determine when to start transmitting information using the eight frequency hopped spread spectrum signal.

The synchronization pulse is only transmitted every few minutes. However, the resolution of the start of the message indicating the synchronization pulse is very accurate, it being transmitted at 0.090000 seconds GPS time after a fixed time of day, such as 12:00 GMT. This GPS time is accurate to at least within 100 nanoseconds.

An overview of the transmission format of the two-way pager is shown in Figure 6. The actual transmission of information from the two-way pager communication devices 114 is done using Differential Bi-Phase Shift Keying (DBPSK) modulation on a frequency hopped carrier of less than one watt. The transmission of information from the two-way pager communication devices 114 on the frequency hopped carrier may also be done using Frequency Shift Keying (FSK) modulation. Typically a single transmission consists of 53 hops or 53 changed frequencies selected from a list of narrow band frequencies. The frequency selection is based on a pseudo-random noise code list pointing to the frequency selection list. The synchronization information tells the two-way pager 114 where along the pseudo random noise code it should be synchronized for transmission of its message and the fine synchronization information tells exactly the time of day so that the two-way pager 114 knows exactly when to start transmitting the specific frequency so that the two-way paging terminal 110 is looking for that frequency at the same time.

In operation, 200 frequencies are used by the two-way pager 114 and the base stations and internally stored in a list numbered F1 through F200. For a specific message, 53 frequencies will be used to transmit the entire

message. These 53 frequencies are selected based on a 1,000 member pseudo-random noise code.

The use of the accurate synchronization signal periodically broadcast via the outbound paging signal enables the two-way pager communication devices to use lower accuracy components thus reducing the manufacturing cost of two-way pager communication devices. For example, high accuracy crystals to track the time of day within the microprocessor are available with an accuracy of three parts per million. Thus, a time drift of approximately three micro seconds per second or 180 microseconds in a minute is the known drift. There are also time inaccuracies which are introduced due to the time of transmission (variable path length) from the source from the two-way paging terminal when the synchronization information is sent. By employing crystals which are cheaper and have an accuracy of the order 50 parts per million, the amount of time-of-day drift normally wouldn't be tolerable. However, by using the synchronization information transmitted on a regular basis from the two-way paging terminal, the microprocessor can continually correct its own internal day clock so that accurate time of day measurements are always maintained. The microprocessor estimates the momentary inaccuracy of the crystal by tracking the drift across several synchronization transmissions and dynamically adjusts for the frequency drift of the crystal and the offset using internal offset registers for accurate time of day information.

Counters are employed within each microprocessor of the two-way paging units to compensate for the offset of the frequency based on the synchronization time information. There are generally two major factors which affect the drift in a crystal: temperature and acceleration. Most of the drift is due to temperature, and the remaining drift components are negligible. The frequency drift in a crystal due to temperature is very slow, on the order of 50 Hz over 10 seconds. During a single day the temperature can change by 20 or 30 degrees Fahrenheit, requiring a time update from the GPS clock approximately every five minutes.

Two-Way Pager Transmission Format

The signal sent from the two-way pager 114 to the base stations is a spread-spectrum, frequency-hopped transmission using differential bi-phase shift keying (DBPSK) modulation on the frequency-hopped carrier to transmit digital information. The transmission of information from the two-way pager communication devices 114 on the frequency hopped carrier may also be done using Frequency Shift Keying (FSK) modulation. The frequency hops are relatively slow, the frequencies transmitted are very narrow and the transmission power is extremely small. The maximum peak output power of transmission from two-way pager 114 is limited to less than one watt to allow use of the 902-928 MHZ band in the United States without the need for licensing the paging transmitters as allowed by FCC regulations defined in 47 C.F.R. §15.247. Those skilled in the art will readily recognize that other frequency bands and transmissions power levels may be employed depending upon FCC licensing requirements or other frequency licensing requirements of other nationalities.

The use of an accurate crystal to control each frequency of transmission is required within each two-way paging unit 114. For example, high accuracy crystals to transmit the narrow bandwidth frequencies used for the frequency hopped transmissions are available with an accuracy of three parts per million. At 900 MHZ, a 3 ppm drift would place a single frequency somewhere within a 2.7 KHz band. To tolerate frequency drift due to aging and temperature, each individual frequency of the frequency hopped signal is allocated to a 7.5 KHz band or channel, even though the actual frequency is on the order of 200 Hz wide skirt within this 7.5 KHz allocated bandwidth. Those skilled in the art will readily recognize that by using alternate components, the frequency channels (individual frequency of the frequency hopped signals) of 7.5 KHz allocated bandwidth may be wider or more narrow depending upon the overall allocated bandwidth for the system. For example, 1 KHz or less bands may alternatively be allocated per channel.

Tests on this invention have shown that by processing the received signals at the base stations entirely in the digital domain using the

combination of unique Fast Fourier Transform algorithms of the present invention to locate and retrieve the frequency hops and by using a combination of unique confidence algorithms with a plurality of error correction codes, the receiving base station is able to pull the response information from a very low power signal from a distance of up to 45 kilometers (28 miles) in a flat terrain. In a rather noisy urban environment, a range of 24 kilometers (15 miles) is the norm. The information within the signals is accurately decoded even though direction of the incoming signals may be severely distorted due to multi-path reflections and noise.

As shown in Table 1, the two-way pager message format consists of a preamble and the message body spanning a total of 53 frequency hops. Those skilled in the art will readily recognize that longer messages may be transmitted using the preferred embodiment of the present invention, and the messages format described here is illustrative but not limiting. Since FCC regulations defined in 47 C.F.R. §16.247 require a minimum of 50 frequency hops, the 53 hop message format described here is considered a short message hop. Much longer message hops to transfer more digital data is also implemented but not described here. Of course, those skilled in the art will readily recognize that shorter messages than those described below are equally possible for the preferred embodiments of the present invention. The message length and number of transmission hops are a matter of design choice.

The message preamble consists of a predefined code of ones and zeros to get the attention of the base unit receiver to begin its FFT (Fast Fourier Transform) routines to begin pulling the message out of the noise. The preamble consists of 165 bits transmitted across 5 hops, that is, transmitted using DBPSK (Differential Bi-Phase Shift Keying) or Frequency Shift Keying (FSK) on five different frequencies selected from the frequency list with the specific frequencies selected based on the PN (Pseudo-random Noise) Code list stored within the two-way pager. The sequence location within the PN code that the two-way pager will begin to follow is based on the synchronized time of day.

Within a single hop (a single carrier frequency), the carrier phase is modulated 33 times to encode the predefined one-zero pattern of the preamble.

The message body follows the preamble and consists of three groups of data. Each group consists of 30 actual data bits so that the entire message is, in the preferred embodiment of the present invention, 90 total data bits (although other bit length messages may be chosen). The actual data encoded within these 90 bits is described above and may be in any convenient coded format. Those skilled in the art will readily recognize that a wide variety of message formats and encoding of the data bits may be used without departing from the spirit and scope of the present invention. The encoding described here, however, has been proven effective in retrieving the data bits buried in background noise with a high degree of accuracy and a low actual error rate.

TABLE 1: Two-Way Pager Message Format

```
Preamble is 165 bits (33 bits x 5 hops)
Message is 512 transmitted bits
(Message is 90 bits actual data)

□ = One Frequency Hop

| preamble | Message Body Spread Over 48 Hops |
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<u>Outer Message Coding</u>

Each of the three groups of message data (30 bits each) are BCH encoded using a standard 30,63 BCH code and with a single parity bit added to form a 64-bit word. This encoding decreases the error rate from 10^{-2} to 10^{-5}. This encoding, documented and understood by those skilled in the art, can correct up to 6 errors or detect up to 13 errors. Detection of corruption of a data word that cannot be reconstructed will cause the base to request a second transmission of the acknowledgment message.

Inner Coding and Interleaving

The inner coding of the message will protect the integrity of the message with an error rate as high as 25%. Each block of 64 bits of data (corresponding to a groups of 30 bits and earlier encoded by a standard 30,63 BCH code) is split into two sub-blocks of 32 bits (sub-blocks A and B of Table 2), and a reference bit is added to each sub-block to assist the differential encoding to provide a reference bit to the DBPSK or FSK decoder. The 33 bit sub-blocks are transmitted over one frequency hop each and are replicated 8 times so that the 64-bit block traverses 16 frequency hops. In transmission, the 33 bit sub-blocks are interleaved to further reduce loss of data, as shown in Table 3, where sub-blocks A and B of Table 2 correspond to the first group of 30 bits, sub-blocks C and D, correspond to the second group of 30 bits, etc. The total message is 53 hops where each hop is 180 msec in length making the duration of a single message 9.54 seconds.

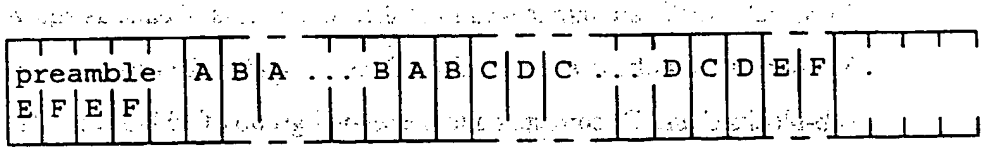
TABLE 2: Interleaving Format for Sub-block

A = 1 reference bit and 32 data bits = 33 bits
B = 1 reference bit and 32 data bits = 33 bits
□ = One Frequency Hop

A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B

TABLE 3: Inner Coding and Interleaving of Sub-blocks

A = first 33 bits of 1st block
B = second 33 bits of 1st block
C = first 33 bits of 2nd block
D = second 33 bits of 2nd block
E = first 33 bits of 3rd block
F = second 33 bits of 3rd block
☐ = One Frequency Hop



Those skilled in the art will readily recognize that a wide variety of data interleaving may be utilized to effect better error tolerance and may be substituted for the interleaving described here. Such alternate substitute interleaving means are CIRC (Cross Interleaved Reed Solomon Code) used in CD (Compact Disc) recording media operating either at the block level or at the bit level.

<u>Single Hop Format</u>

The acknowledgment signals are transmitted by the two-way pager communication devices 114 in a 1.5 MHZ band selected from within the 902-928 MHZ spectrum. The 1.5 MHz band is divided into 7.5 KHz channels to provide 200 channels available in which the frequency hops can occur. Thus, each frequency hop is a channel 7.5 KHz wide in which a carrier frequency is transmitted. For example, channel one will have a frequency F1 at 902.000000 MHZ +/- 3.25 KHz, channel two will have its center carrier frequency at 902.007500 MHZ +/- 3 KHz, etc.

Each transmit frequency of each hop will thus be centered at the approximate mid-point of the assigned channel band; however, due to inaccuracies in the two-way pager circuits and reference crystals, the actual

transmit frequencies will vary between units. If high quality crystals are used to accurately produce the required frequencies, very little drift off the center frequency will result. In the preferred embodiment of the present invention, low cost crystals are purposely employed to keep the per-unit manufacturing costs down. This will allow for a lower-cost product sold to the user which will increase market penetration. Thus, reference crystals are preferred which have a frequency accuracy of 3 ppm such that at 900 MHZ, the statistical drift would be approximately 2700 Hz. The crystals center frequency within its nominal accuracy also drifts due to aging and temperature variations, but this drift is slow compared to the transmission times so the drift during a single transmission due to these latter variants is unimportant.

A single frequency hop is shown in Table 4. The 15 millisecond guard time preceding each hop is primarily a settling time for the oscillator circuits of the two-way pager communication devices to allow the internal oscillator circuit to lock onto the new frequency between hops. Each hop is transmitted at a single frequency in which the phase of the carrier is either at 0 degrees phase or 180 degrees phase in reference to the phase of the reference bit immediately following the quiet or guard time. Thus the first bit is a phase reference bit followed by 32 data bits exhibiting either zero phase shift or 180 degree phase shift to encode the data bits as DBPSK (Differential Bi-Phase Shift Keying). In an alternative implementation, each frequency hop may be modulated using Frequency Shift Keying (FSK) in which two frequencies are used to transmit data bits. One hop frequency may indicate a logical one while a second hop frequency may indicate a logical zero. The frequency shift is minor and the frequency differential is contained within a single hop channel.

Each bit of DBPSK or FSK is a transmission of approximately 5 milliseconds of the hop carrier frequency either in phase with the reference bit transmission or 180 degrees out of phase. Each actual bit is approximately 4.7 milliseconds of carrier at the hop frequency preceded and followed by approximately 0.15 milliseconds of quiet guard band to reduce discontinuities

between phase changes which contribute to step-function noise in the transmission.

TABLE 4: Single Frequency Hop Format

Guard time (quiet) = 15 ms
Single Bit = 5 ms of carrier DBPSK / FSK
33 Bits plus guard time = 180 ms

15ms Guard Time	5ms Ref Bit	5ms 1st Bit	5ms 2nd Bit	5ms 3rd Bit	---	5ms 31st Bit	5ms 32nd Bit

Frequency Hopping Sequence

All of the two-way pager communication devices in the market serviced by the two-way paging terminal for message or location finding use the same pseudo random noise code to determine the frequency hops. The pseudo random noise code is a digital code which is repeating after approximately 1,000 unique codes. In the preferred embodiment of the present invention, the pseudo random noise code is stored in memory of each of the two-way pager communication devices. Those skilled in the art will readily recognize, however, that a linear feedback shift register could be used to generate the pseudo random noise code on a real-time basis instead of using a look-up table which is presently in the preferred embodiment.

The PN (pseudo-random noise) code list is stored in memory and maps to a frequency list. In the preferred embodiment of the present invention, the PN code list has 1,000 entries which repeat as a sequence. The control means of the two-way paging units continuously maintain a count of the proper location within this list for the exact time of day. As described below, the time of day for all two-way pager communication devices in the market served by the base terminal are periodically synchronized to ensure acknowledgment messages are synchronized to transmit the hop frequency at the proper time and to

synchronize the location within the PN code list that each two-way pager will use to transmit.

The 1,000 member PN code list maps to a 200 member frequency list. In order to allow a large number of two-way pager communication devices to simultaneously operate in the same geographic market, the two-way pager communication devices are divided into groups and the groups are assigned different sequence segment locations in the same 1,000 member PN list. Thus a two-way pager from group one will begin transmitting a hop at a frequency determined from a first location with the PN code, while a two-way pager from group two may begin transmitting a hop at a frequency determined from a second location in the PN code. The two-way pager communication devices from group one and group two will complete their respective acknowledgment messages in 53 hops. Preferably, the sequence of the PN code used to determine the frequencies of the 53 hops for the two-way pager of the first group will not overlap the sequence of the PN code used to determine the frequencies of the 53 hops for the two-way pager of the second group. More preferable, the frequencies chosen based on the non-overlapping segments of the PN code list are orthogonal such that the same frequency is never used by two two-way pager communication devices belonging to different groups.

In the preferred implementation, the 1,000 member PN code list is divided into 160 hopping sequences. The remote paging units are divided into 40 groups with the members of each group synchronized to track the same location in the PN code list. The microcontroller of each two-way pager, regardless of its group membership, continuously runs through the repeating PN code sequence to stay in synchronization with the base unit and all other two-way pager communication devices. Each group of two-way pager communication devices is further divided into four subgroups such that the two-way pager communication devices within each subgroup are assigned one sequence within the PN code list. Although the 53 hop sequence needed for each acknowledgment transmission may overlap the 53 hop sequence used by a two-way pager in another subgroup, the transmission sequences of a two-way pager

of one group is chosen to not overlap the 53 hop sequence used by a two-way pager in another group.

Direction Finding Base Station Design

As described above, the analysis and decoding of the signals received by the base stations from the two-way pager communication devices is done almost entirely in the digital domain. The carrier frequencies of the frequency hops are down-converted to a lower frequency in each base station and are then digitally sampled. The digital samples are then processed to locate the phase information of interest for direction finding and message decoding. Each base station is constructed with a plurality of digital signal processor pipelines which enable simultaneous message decoding and direction finding of a plurality of simultaneously transmitting two-way pager communication devices.

As shown in Figure 7, the receiving antennas of the base stations are constructed using a plurality of dipole antennas 401a, 401b, though 401n (generally referred to as 401) arranged in an array, as shown in Figure 7 and a single reference omni antenna 404. The omni antenna 404 is not necessary for the preferred embodiment of the present invention since any one of the dipole antennas of Figure 7 may act as a reference antenna for any of the other antennas. The omni reference antenna 404 is used as a reference antenna because the omni antenna 404 exists as part of the two-way paging infrastructure upon which the present invention relies and is used for receiving the messages from the two-way pager communication devices.

In the preferred embodiment of the present invention, the direction finding (DF) antennas of each base station uses twenty-four sector direction finding dipole antennas 401 arranged in four linear arrays as shown diagrammatically in Figure 7. Each of the four linear arrays consists of six dipole antennas. The phase between the antennas is measured indirectly - each instant of time one of the 24 antennas is selected and its phase is compared to the omni antenna.

The switching of the antennas is done every one bit (5 milliseconds) of every frequency hop and is synchronized to the incoming data.

The switching occurs at the 0.7 millisecond gap between the transmission of the bits. The antennas 401 are continuously scanned since there could be many two-way pager communication devices transmitting simultaneously from different directions. Differentiating between the various simultaneously transmitting two-way pager communication devices is capable. If the simultaneously transmitting two-way pager communication devices belong to different groups, they will be using orthogonal frequencies because they are using different sequences in the PN code. If the simultaneously transmitting two-way pager communication devices belong to the same group, they are nonetheless distinguishable due to the particular unique frequency offsets caused by the frequency drift off center frequency of the transmitter reference crystal. As described in the above referenced parent application, the simultaneously received signals may be transmitted within the same 7.5 KHz channel during a hopping sequence of two-way pager communication devices from the same group, but the base stations are capable of distinguishing and tracking the hops of the simultaneously transmitting two-way pager communication devices. This is due to the resolution of the Fast Fourier Transforms (200 Hz bins) used in the pipelined receivers, the narrow frequency skirt of the transmitters in the two-way pager communication devices and the drift tracking performed in the base stations which can distinguish the unique transmission signatures of the simultaneously transmitting two-way pager communication devices.

The direction finding process, described more fully below, compare the exact phase amplitudes of each of the dipole antennas of the four arrays to the phase amplitude at the reference antenna. In the antenna array shown in Figure 7, a circle surrounding the array is divided into eight sectors. The actual direction computation is done in the sectors according to Table 5.

TABLE 5: Sector Allocation on the DF Antenna Array

30° to 60° - top and left arrays
60° to 120° - left array
120° to 150° - left and bottom array
150° to 210° - bottom array
210° to 240° - bottom and right array
240° to 300° - right array
300° to 330° - right and top array
330° to 30° - top array

Those skilled in the art will readily recognize that the whole direction finding array does not have to be installed in a single location. For instance, each linear array of six dipole antennas could be installed on a different face of roof of a high rise building. In some cases a two-way pager cannot transmit from specific sector. For instance one of the sectors faces the sea. In that case the direction finding array could be reduced, and only a single direction finding antenna will be installed at that sector. Usually the interferometer does not operate in case that a two-way pager is very close to the base station (less than 1 kilometer). In such a condition, the other base stations will still perform the direction finding and the central site will still be able to perform the triangulation.

For the reasons exemplified more fully below, the spacing of the six dipole antennas in each of the four sides of the array is critical to maintaining a low degree of ambiguity in direction finding and multi-path rejection. The base ratios of the base lines was found by simulations with several relative prime numbers and is selected to be 6 : 10 : 4 : 3 : 5 to produce a phase gain PG = 56π. The ratio was computed through extensive simulations. Although the spacing between the various antenna is critical to accurate determination of the incident angle of the carrier, the order of the spacing of the antennas in the array is not critical. The order chosen here was based primarily upon a physical implementation consideration that the array frame be mechanically balanced.

Interferometric Direction Finding

The direction finding technique used in the preferred embodiment of the present invention is performed by measuring the electrical phase difference between the antenna of the array caused by the angle of the incoming wavefront of the spread spectrum frequency hopped signal. In ideal conditions where there is no multi-path disruptions of the wavefront, the incoming wave from the two-way pager is coming in angle of θ from the perpendicular line to the base line on which the antennas are mounted.

Figure 8 is an example of how the interferometric direction finding technique of the preferred embodiment of the present invention is practiced. Figure 8 shows, by way of example and not by limitation, only three antennas of the array. The three antennas are used to determine phase differences of the incoming signals between pairs of the antenna. As described above, the phase difference may also be measured between each antenna and a reference antenna such as the omni antenna.

The interferometer direction finding (DF) technique calculates the direction of arrival of the wavefront by measuring the phase of the incoming wave front in several places in space. This interferometric method is a planar interferometric method which assumes that the antenna array and the transmitting two-way pager are all in the same relative plane. Differences in height of the two-way pager and the antenna array are ignore and cause little error in the direction finding of the present invention.

As seen from Figure 8, the three antenna 501, 502 and 503 are irregularly spaced such that distance D_{23} between antennas 501 and 502 is great than distance D_{12} between antennas 502 and 503. The distance between the antennas is selected to be a multiple of a prime number sequence to ensure an irregular spacing of all antennas in the array which increases the probability that an electrical phase difference will always be measured between some of the antenna members of the array. The distance between the antennas is important to minimize ambiguity errors in measuring the phase of the incoming wavefront. If the antennas are spaced too widely apart, there is increased ambiguity in

determining whether the phase difference of the same wavelength is being compared or whether the phase of different wavelengths are being mistakenly compared. Since the frequency hopped spread spectrum signal of the present invention is selected to operate in the 900 MHZ band, the wavelength λ of the incoming signal is approximately 30 centimeters.

Again, referring to Figure 8, the phase difference between the two antennas 502 and 503 is know as D_{12} and the formula for measuring the angle of the incoming signal is :

(1) $$(\varphi_{12} + 2\pi K_{12})/2\pi = D_{12} SIN(\theta)/\lambda$$

where

θ is the angle of the incoming wavefront measured from the perpendicular of the antenna array baseline,

φ_{12} is the electrical phase measured between antennas 502 and 503

K_{12} is an ambiguity factor since the system is capable of measuring φ between $\pm\pi$ since the antennas could be measuring the phase difference of more than one cycle λ,

D_{12} is the distance between the antennas 502 and 503, and

λ is the wavelength of the incoming signal.

According to this formula, as long as D_{12} is smaller than $\lambda/2$, the ambiguity factor K_{12} equals 0. Thus the largest antenna spacing in the array is selected to be smaller that 15 centimeters.

In order to estimate the inherent instrumental error of the direction finding interferometer, the above equation can be written in a different form:

(2) $$SIN(\theta) = (\varphi_{12} + 2\pi K_{12})/(2\pi D_{12}/\lambda)$$

Assuming that all the errors in estimating θ is due to inaccuracies in estimating φ, differentiating the above equation produces:

(3) $$\sigma(\theta) = \sigma(\varphi_{12})/(2\pi D_{12} COS(\theta)/\lambda)$$

where σ is the standard deviation.

From this equation, inherent limitations in the system are determined. The electrical error is divided by the factor $2\pi D_{12}/\lambda$ which is termed the phase gain (PG) which reduces the error by the ratio between the distance and the wave length. Also, the error rapidly grows to infinity as θ approaches 90°. Thus the coverage of the present linear interferometer is limited to ± 60° as shown by the division of the array into sectors described in above in conjunction with Table 5. In order to reduce the error, the phase gain must be made as large as possible and each antenna face of the antenna array of the present linear interferometer array covers only 1/4 of the space. The antenna spacing in the array must have a distance smaller than $\lambda/2$ in order to resolve ambiguities.

Ambiguities in Interferometric Direction Finding

There are two types of ambiguities in interferometer DF: front to back ambiguities (the linear interferometer only covers effectively 1/3 of its surrounding area) and multiple possible solutions of the interferometer equations, in case where the distance between two antennas is greater than $\lambda/2$. This latter ambiguity is caused by measuring the phase difference between different cycles of the incoming wavefront.

The front to back ambiguity is solved in the present invention by using multiple arrays, as shown in Figure 7. In order to cover 360°, the present invention uses four sub-arrays of six dipole antennas each, for covering 90°. The antennas in each array have a vertical beam width of 120°. The base station scans all the antennas of the array through the 1:24 antenna selector 402 and selects the proper sub-array by comparing the amplitudes received from antennas in each array. If two arrays are almost equal in amplitude (within 3 dB), then the interferometer process is done on both arrays and the direction of arrival (DOA) of the signal is computed either from both or from the proper array which is selected according to the DOA closer to its perpendicular.

The multiple cycles ambiguity is solved by using more than two antennas in each linear array. By way of example, but not by limitation, a three antenna array is as shown in Figure 8. The distances between the antennas that

are elected as $D_{12}=2*\lambda/2$ and $D_{23}=3*\lambda/2$. Using these ratios, the equation labeled (2) above becomes:

(4) $$SIN(\theta)=\varphi_{12}/2\pi+K_{12}$$

(5) $$SIN(\theta)=\varphi_{23}/3\pi+2K_{23}/3$$

Figure 9 is an ambiguity plane plot of the three antenna array of Figure 8. Figure 9 shows the phase difference φ_{12} plotted against the phase difference φ_{23} as an interferometer ambiguity plane plot. Figure 9 shows a family of lines, 601, 602, 603, 604, and 605, parameterized by K_{12} & K_{23} with the same slope created as θ moves from 0° to ±90°. The following formula are used to create the plane plot of Figure 9:

$$(\varphi_{23}/3\pi)+2K_{23}/3=(\varphi_{12}/2\pi)+K_{12}$$

The ambiguity resolution algorithm is as follows. The phase difference between the antennas is measured as φ_{12} and φ_{23}. On the interferometer ambiguity plane of Figure 9, find the line represented by K_{12} and K_{23} (ambiguity factors) that has the minimal distance, which is the actual probability distance, to φ_{12} and φ_{23}. After solving the ambiguity, compute the exact DOA using the full span of the array i.e. 2.5λ which gives a phase gain (PG) of 5π.

One could select ratios of N:N + 1 of λ/2, where N is the number of antennas in the array. This ratio of N:N + 1 of λ/2 may be selected to be as large as possible in order to improve the phase gain. But as N gets larger, the distance between the ambiguity lines gets smaller and the algorithm becomes vulnerable to an error in the proper selection of K_{12} and K_{23}. The result will be a gross error.

If the measurements distribution of φ is gaussian, then in order to compute the gross error probability, the "tail" of the gaussian distribution from the distance between the ambiguity lines to "infinity" must be computed since the phase is folding after ± π. This computation described above is only an

approximation and is almost true for small values of $\sigma(\varphi)$ which is true at high signal to noise ratio (SNR) or high signal to interference ratio. For white gaussian noise, $\sigma(\varphi)$ could be approximated by $1/\sqrt{SNR}$ where SNR is the signal to noise ratio.

Figure 10 is the ambiguity plane for the ratios 5:6 of $\lambda/2$. The distance between the ambiguity lines became less than half compared to the ratio of 2:3 which practically increased the gross error to be impractical. Thus, the solution is to add more antennas to the array. Adding more antennas at different ratios spreads out the ambiguity lines in hyper space (multi-dimensional space) with dimension of N-1 (N - number of antennas in the array) and increases the distance between them. In the preferred embodiment of the present invention, it was concluded that in an urban environment six antennas are required in a linear array resulting in a five dimensional plot of Figure 6 (which is incapable of being shown in a drawing). The following formula are used to create the plane plot of Figure 10 which is an example of moving the antenna spacing closer together:

$$SIN(\theta)=(\lambda/D_{12})*(\varphi_{12}+2\pi K_{12})/(2\pi)=(\varphi_{12}/5\pi)+2K_{12}/5$$

$$SIN(\theta)=(\lambda/D_{23})*(\varphi_{33}+2\pi K_{23})/(2\pi)=(\varphi_{23}/6\pi)+K_{23}/3$$

$$(\varphi_{23}/6\pi)+K_{23}/3=(\varphi_{12}/5\pi)+2K_{12}/5$$

Multi-Path Error Sources in Interferometric Direction Finding

The preferred embodiment of the present invention provides accurate direction finding and location in urban areas. The major source of error is multipath distortion in which the incoming wave front is impaired by reflections coming from different directions. Figure 11 is an example of multi-path reflections in an urban environment. The unique feature of frequency hopping enables the interferometer system of the present invention to distinguish between the principal reflection and other reflections. Since it is not guaranteed that a line of sight exist between the two-way pager and the base station due to multi-path reflections, the most consistent reflection through the hopping message is the one closest to the real bearing. Empirical testing and observations

proved that the bearing error is in practice the size of the "urban block" from which the two-way pager transmits. In practical tests in an urban environment, the urban block size was about 75 meters in average, and up to 200 meters peak error.

Multi-Path Resistant Direction Finding Algorithm

The full direction finding algorithm relates to measurements of a linear antennas array having six dipole antennas per side of a four-sided array with a single omni reference antenna (see Figure 7). The calculations are performed on a six antenna subarray after the sub-array is selected to be closest to the two-way pager as described above in conjunction with Table 5. The full interferometer formula for a six antennas sub-array is:

(6)
$$\begin{vmatrix}\varphi_1\\ \varphi_2\\ \varphi_3\\ \varphi_4\\ \varphi_5\end{vmatrix} = \frac{2\pi}{\lambda}\begin{vmatrix}D_1\\ D_2\\ D_3\\ D_4\\ D_5\end{vmatrix} SIN(\theta) + 2\pi\begin{vmatrix}K_1\\ K_2\\ K_3\\ K_4\\ K_5\end{vmatrix} + \begin{vmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \varepsilon_4\\ \varepsilon_5\end{vmatrix}$$

where

φ_i is the electrical phase measured between the antennas,

D_i is the distances between the antennas

λ is the wavelength

θ is the direction of arrival (DOA)

K_i is the ambiguity factor, integer value such that,

$$-\pi < 2\pi D_i * SIN(\theta) / \lambda + 2\pi K_i < \pi$$

ε_i is the additive noise (assumed to be gaussian).

To solve the equation is (6) above, linear array calculations are performed to solve the following vector values:

(7)

$$\underline{\varphi} = \begin{vmatrix} \varphi_1/2\pi \\ \varphi_2/2\pi \\ \varphi_3/2\pi \\ \varphi_4/2\pi \\ \varphi_5/2\pi \end{vmatrix} ; \underline{d} = \begin{vmatrix} 2D_1/\lambda \\ 2D_2/\lambda \\ 2D_3/\lambda \\ 2D_4/\lambda \\ 2D_5/\lambda \end{vmatrix} ; \underline{K} = \begin{vmatrix} K_1 \\ K_2 \\ K_3 \\ K_4 \\ K_5 \end{vmatrix} ; \underline{E} = \begin{vmatrix} \varepsilon_1/2\pi \\ \varepsilon_2/2\pi \\ \varepsilon_3/2\pi \\ \varepsilon_4/2\pi \\ \varepsilon_5/2\pi \end{vmatrix}$$

$$X \equiv 0.5\ SIN(\theta)$$

$$\underline{\varphi} = \underline{d}\ X + \underline{k} + \underline{E} \Rightarrow \underline{\varphi} - \underline{k} = \underline{d}\ X + \underline{E}$$

The results of these calculations are as follows:

the vector elements $\underline{\varphi}$ are limited by: $| -0.5 < \varphi_i < 0.5 |$;

$\underline{\varphi}$ is the measurements vector and $\underline{d}$ is known;

$-0.5 < X < 0.5$; X is unknown;

$\underline{k}$ is unknown; its elements are integer, limited by the elements of $\underline{d}$.

$\underline{E}$ is the noise vector that is unknown.

In the calculations, it is assumed that the noise is additive such as:

$$E\{\phi_i \phi_j\} = \begin{cases} 0 & i \neq j \\ \sigma^2 & i = j \end{cases}$$

$$E\{\varepsilon_i\} = 0;\ i \in (1,2,3,4,5)$$

(8)

$$E\{\varepsilon_i * \varepsilon_j\} = \begin{cases} 2\sigma^2 & i=j \\ -\sigma^2 & i=j-1 \\ -\sigma^2 & i=j+1 \\ 0 & otherwise \end{cases}$$

$$R = COV\left(\underline{\varphi}\right) = \left(\frac{\sigma}{2\pi}\right)^2 \begin{bmatrix} 2 & -1 & 0 & 0 & 0 \\ -1 & 2 & -1 & 0 & 0 \\ 0 & -1 & 2 & -1 & 0 \\ 0 & 0 & -1 & 2 & -1 \\ 0 & 0 & 0 & -1 & 2 \end{bmatrix}$$

Where :

ϕ_i is the electrical phase measured at antenna i.

$\varphi_i \equiv \phi_i - \phi_{i+1}$

The solution to this equation is to search among all $\underline{K} \in N$, the specific $\underline{K}$ that minimizes a weighting function in a weighted least square procedure (WLS). For every $\underline{K} \in N$ we compute:

(9)

$$\hat{X}(\underline{K}) = \frac{\underline{d}^T R^{-1}}{\underline{d}^T R^{-1} \underline{d}^{-1}}\left(\underline{\phi} - \underline{K}\right) = H\left(\underline{\phi} - \underline{K}\right)$$

The error will be:

(10)
$$\underline{\epsilon}(\underline{K}) = \underline{\varphi} - \underline{d}\hat{X}(\underline{K}) = \left(I - \frac{\underline{d}\underline{d}^T R^{-1}}{\underline{d}^T R^{-1} \underline{d}^{-1}} \right) \left(\underline{\varphi} - \underline{K} \right)$$

Weighting function:

(11)
$$C(\underline{K}) = \underline{\epsilon}^T(\underline{K}) R^{-1} \underline{\epsilon}(\underline{K}) =$$
$$\left(\underline{\varphi} - \underline{K} \right)^T \left(I - \frac{\underline{d}\underline{d}^T R^{-1}}{\underline{d}^T R^{-1} \underline{d}^{-1}} \right)^T R^{-1} \left(I - \frac{\underline{d}\underline{d}^T R^{-1}}{\underline{d}^T R^{-1} \underline{d}^{-1}} \right) \left(\underline{\varphi} - \underline{K} \right) =$$
$$\left(\underline{\varphi} - \underline{K} \right)^T A \left(\underline{\varphi} - \underline{K} \right)$$
$$A = \left(I - \frac{\underline{d}\underline{d}^T R^{-1}}{\underline{d}^T R^{-1} \underline{d}^{-1}} \right)^T R^{-1} \left(I - \frac{\underline{d}\underline{d}^T R^{-1}}{\underline{d}^T R^{-1} \underline{d}^{-1}} \right)$$

Where A is 5 X 5 matrix. The rank of A is only 4. In order to reduce the amount of real time computation, the following computations are performed and the results stored:

(12)
$$A = F^T F$$
$$A = A_V A_Q A_V^T$$
$$\left[A_V A_Q \right] = eig(A)$$
$$F = A_Q^{1/2} A_V^T$$

Since the rank of A is 4, one of the eigenvalues and thus the corresponding eigenvector are 0. Matrices 4x5 and 5x4 are created and designated by a ~ over the top of the matrix identifier and thus:

(13)
$$A = \tilde{F}^T \tilde{F}$$
$$F = \tilde{A}_Q^{1/2} \tilde{A}_V^T$$

Using these values in the weighting function produces:

(14)
$$C(\underline{K}) = \left(\underline{\varphi} - \underline{K}\right)^T \tilde{F}^T \tilde{F} \left(\underline{\varphi} - \underline{K}\right)$$

$$\underline{\tilde{\varphi}} = \tilde{F}\underline{\varphi}$$

$$\underline{\tilde{K}} = \tilde{F}\underline{K}$$

$$C(\underline{K}) = \left(\underline{\tilde{\varphi}} - \underline{\tilde{K}}\right)^T \left(\underline{\tilde{\varphi}} - \underline{\tilde{K}}\right) = \left|\underline{\tilde{\varphi}} - \underline{\tilde{K}}\right|^2$$

The full algorithm thus becomes:

Compute in off-line:

1. *Compute* $\tilde{F}$.
2. *For all* $\underline{K} \in N$ *compute* $\underline{\tilde{n}} = \tilde{F}\underline{K}$.
3. *Compute the matrix* $\underline{H}$.

Compute in real time:

1. Compute:

$$\underline{\tilde{\varphi}} = \tilde{F}\varphi$$

2. For all $\underline{K} \in N$, compute:

$$C(\underline{K}) = \left|\underline{\tilde{\varphi}} - \underline{\tilde{K}}\right|^2$$

3. Find the best three (3) $\tilde{\underline{K}}$ that mostly minimize $C(\underline{K})$. This procedure is done for each hop.

4. Compute $X(\underline{K})$ for those $\underline{K}$ selected.

5. Compute a histogram from all the $X(\underline{K})$, using for each DOA its distance from the lines (weight) in inverse as weight.

6. Filter the histogram by passing a boxcar low-pass filter of 3° over the histogram in order to cancel small peaks in the neighborhood of a real peak.

7. Find the highest peak and the second to the highest peak.

8. Report the results.

<u>Triangulation Process</u>

The input to the location algorithm are reported measured directions from several base stations. Each base station reports two directions. Each direction is reported with its peak heights which is an indication of its validity. The location algorithm projects the direction of the incoming signal on a gnomonic plane tangent to earth, it filters out the false readings, and it computes the most probable location of the two-way pager (vehicle).

<u>Cassini UTM Projection</u>

The solution of triangulation on the earth ellipsoid is a highly non-linear problem. In order to simplify the problem, we transfer the observed data to a plane called the gnomonic plane as shown in Figure 13. The geographic location of the base station on earth is transferred to an X-Y position on the gnomonic plane. Each measured bearing is also transferred to the gnomonic plane with a small adjustment. The estimation process is done on the plane. The estimated location of the two-way pager is not transferred back to an earth ellipsoid since the same plane is used for graphic display of maps using a Microsoft Windows program or the like.

The Cassini UTM projection is widely used for mapping. Its advantages are that the mapping are in the Cartesian coordinate system such that the E-W and N-S lines are orthogonal. The projection maintains approximately both the directions related to the north and the distances at radius less than 50 M.

The projection is very convenient for graphic display such as in the Microsoft Windows format.

The main distortion of the UTM projection is caused by the convergence of the meridian toward the north. There are two corrections that have to be made:

1. Correction of the map north to the geographical north, which is a bias correction; and
2. Small correction of the DOA (direction of arrival of the signal) according to the location of the base station.

In actual observations, the correction was actually measured together with the calibration and measurement of the pointing of the direction finding array toward the north. The calibration was performed relative to known reference point locations in the covered area. To improve system accuracy, a reference transmitter having a known exact location may be used to correct the system parameters.

<u>Direction Finding Fixing on a Plane</u>

The fixing process input are the two DOA received from all the base stations. There are several tests performed on the results received from the BS:

If the peaks are too low, both measurements are ignored.

If the ratio between peaks is larger than 4, the second peak is ignored.

The CS (Central System) computes the fix by using all the combinations from the DOA received from the base stations. Note that within one message there could be several DOAs.

The fixing process is an LMS (least mean square) process in which the most probably point is found. The most probable point is defined as the point on the plane that its sum of the squared distances from all the DOAs is minimal. The process is as follows:

The distance of a point (X,Y) from a DOA is:

(15) $$d_i(X,Y)=(Y-Y_i)\cos(\theta_i)-(X-X_i)\sin(\theta_i)$$

where (X_i, Y_i) are the coordinates of the base station number i.

$d_i(X, Y)$ - distance of (X , Y) from the DOA number i.

θ_i - The angle of DOA number i from the north

(X , Y) - a point on the plane

(15) could be written as:

(16) $$X_i\sin(\theta_i)-Y_i\cos(\theta_i)=X\sin(\theta_i)-Y\cos(\theta_i)+d_i$$

Assuming that M inputs from the base station, ($i \in \{1,......,M\}$), equation (16) is written in a matrix form:

(17) $$\begin{bmatrix} X_i\sin(\theta_i)-Y_i\cos(\theta_i) \\ \cdot \\ \cdot \\ \cdot \\ X_M\sin(\theta_M)-Y_M\cos(\theta_M) \end{bmatrix} = \begin{bmatrix} \sin(\theta_i) & -\cos(\theta_i) \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ \sin(\theta_M) & -\cos(\theta_M) \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} + \begin{bmatrix} d_i \\ \cdot \\ \cdot \\ \cdot \\ d_M \end{bmatrix}$$

where M - number of bases, as shown in Figure 12.

(18)

$$\underline{Z} \equiv \begin{bmatrix} X_i \sin(\theta_i) - Y_i \cos(\theta_i) \\ \cdot \\ \cdot \\ \cdot \\ X_M \sin(\theta_M) - Y_M \cos(\theta_M) \end{bmatrix}$$

$$A = \begin{bmatrix} \sin(\theta_i) & -\cos(\theta_i) \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ \sin(\theta_M) & -\cos(\theta_M) \end{bmatrix}$$

$$\underline{c} \equiv \begin{bmatrix} X \\ Y \end{bmatrix}$$

$$\underline{D} \equiv \begin{bmatrix} d_i \\ \cdot \\ \cdot \\ \cdot \\ d_M \end{bmatrix}$$

$$\underline{Z} = A\underline{c} + \underline{D}$$

Where:

$\underline{z}$ is a vector of M elements.

A is a matrix of M rows, 2 columns.

$\underline{c}$ is a vector of M elements.

$\underline{D}$ is a vector of M elements.

The purpose is to find $\underline{z}$ such that $\underline{D}^T\underline{D}$ will be minimized. The algorithm is LMS, as described above, and is performed by differentiating $\underline{D}^T\underline{D}$ relative to $\underline{c}$ and comparing the result to 0.

Complete Fixing Algorithm

1. Compute all intersections between all probable DOAs using (19).
2. Perform two dimensional filtering over all intersections, taking into account the power of each intersection according to the DOAs power that created that intersection. The filter size is 900 X 900 meters.
3. Find the an intersection from the DOA that are in the filter.

Operation Summary

In summary, and in referring once again to Figure 9, the slope of the lines is 2/3 and the algorithm finds the closest line to the observed point 600. The most probable actual point lies on the line 601. Figure 10 shows the use of more ambiguity lines to get better resolution of the observed point 701. The actual probable location of the observed point would be on the line at position 702 where the slope of each of the ambiguity lines is the distance between the antennas. Thus a closer spacing of the antennas shown at Figure 10 produces less ambiguity as to the observed versus actual angle of the DOA.

The ambiguity lines shown in Figures 9 and 10 are for three antennas. In reality according to the matrices described above, six antennas are used in a five dimensional space which is unable to be drawn in a figure. In a five dimensional space, the observed point is located, and the nearest lines in the five dimensional space are located for the most probable actual DOA for each based station. By spreading out the spacing of the antennas, more ambiguity lines as shown in Figure 10 are used such that antenna spacing is best spread out to minimize ambiguity.

In the based station, the observed point 701 representing DOA θ is compared to the closest three lines in a five dimensional space. A histogram is then generated based on the three lines closest to the observed point. Then a gaussian distribution of the observed θ's is computed and only the actual points 702 and five dimensional space are picked which lie within a single standard deviation. A histogram typically produces two peaks for most probable observed values. Histograms that produce more than two peaks are filtered so that only

the two strongest peaks are taken as potential values. These two most probable actual values of the DOA θ are then sent to the central site for triangulation to determine the position of the transmitter.

Those skilled in the art will readily recognize that the benefit of the histogram analysis may be achieved through a less computation intensive operation known as K/m where the DOA θ most often occurring in the analysis is the most probable DOA θ. A complete histogram need not be computed if instead a statistical threshold is applied in which the number of occurrences of θ exceeds a threshold value. As soon as the threshold value is reached, further analysis is halted since the most probable θ has been found.

At the central site, the two most probable θ for the two histogram peaks around a plus or minus three degree range are recorded for two, three or more base stations. Thus 2^n most probable points are received by the base station whereas n is equal to the number of stations. Thus if four stations are reporting, two most probable DOA θ, 16 observed points are received at the central station. A spacial filter is used with a 900 by 900 meter space to determine which of the points cluster within the most probable location. Within this 900 square meter space, the most probable location is selected. Additional computation can be made by overlaying the 900 by 900 square meter space onto a map of an urban area and, for vehicle location, determining that the vehicle could only be on a street and not within a building. In actual observations, the actual location of the two-way pager is within a 77 square meter area.

Thus the multipath problem is solved through the use of a multidimensional ambiguity space to eliminate observed DOA values which are least probable. The use of a plurality of arrays will produce a number of observed values within the n-dimensional ambiguity space, some of which are due to the actual direction of arrival and some of which are due to multipath reflections. Since the observed values in the preferred embodiment of the present invention are the result of multiple frequencies in a frequency hopped spread spectrum system, observed values and most probable values will be calculated at various frequencies. Different frequencies observed over a period

of time may be more or less susceptible to the multipath problem. In addition, for a moving two-way pager, the doppler shift will be observed but minimized over time since only the most probable values due to the strongest signals will survive a histogram analysis. Thus the histogram analysis should be performed over a number of frequency hops over a longer period of time until the multipath signals statistically drop out. Thus only the true direction signals will survive the histogram analysis and will be passed to the central station for final analysis.

CONCLUSION

Although specific embodiments have been illustrated and described herein, it will be appreciated by those of ordinary skill in the art that any arrangement which is calculated to achieve the same purpose may be substituted for the specific embodiment shown. For example, the present system may operate where the vehicle owner only has a one-way conventional pager and the vehicle owner contacts the central paging center using a cellular or conventional telephone. Also, the present invention is not limited to the use of frequency hopping spread spectrum signals on the uplink from the vehicle. As described above, the present invention will operate using two-way communication systems based on alternate communication protocols and mediums. Also, the present invention is not so limited to interferometric direction finding. Other techniques may be used such as differential ranging, differential time-of-arrival, GPS, dead reckoning, etc. Thus, this claims of the present invention are intended to cover any adaptations or variations of the present invention. Therefore, it is manifestly intended that this invention be limited only by the claims and the equivalents thereof.

WHAT IS CLAIMED IS:

1. A vehicle monitoring system, comprising:

a status indicator connected to a vehicle and operable to detect an occurrence of an event within the vehicle;

a first transmitter connected to the status indicator and operable for transmitting a message indicating the occurrence of the event;

at least one receiver operable for receiving the message and connected to a central station for centrally receiving the message;

a second transmitter connected to the central station for re-transmitting the message as a forwarded message; and

a pager operable for receiving the forwarded message.

2. The vehicle monitoring system of claim 1, wherein the status indicator is a theft alarm.

3. The vehicle monitoring system of claim 1, wherein the pager is a two-way pager which is further operable for transmitting a command, wherein the at least one receiver is further operable for receiving the command, and the central station is further operable for forwarding the command to the vehicle via the second transmitter.

4. The vehicle monitoring system of claim 1, wherein the central station is further operable for determining location of the vehicle.

5. The vehicle monitoring system of claim 4, wherein the at least one receiver is a plurality of receivers which are operable for determining the incident direction of the message and wherein the central station performs triangulation to determine the location of the vehicle.

6. The vehicle monitoring system of claim 5, wherein the plurality of receivers are further operable for determining the incident direction of the message by interferometric direction finding.

7. The vehicle monitoring system of claim 1, wherein the a first transmitter is operable for transmitting a message using frequency hopped spread spectrum signals.

8. The vehicle monitoring system of claim 3, wherein the two-way pager is operable for transmitting a command using frequency hopped spread spectrum signals.

9. The vehicle monitoring system of claim 3, wherein the two-way pager transmits the command to control a function within the vehicle.

10. A vehicle theft monitoring and location system, comprising:

a theft indicator connected to a vehicle and operable to detect an unauthorized entry or use of the vehicle;

a first transmitter connected to the theft indicator and operable for transmitting a theft alert message;

at least one receiver operable for receiving the theft alert message and connected to a central station for sending the theft alert message to the central station;

at least one paging transmitter connected to the central station for re-transmitting the theft alert message as a forwarded theft alert message;

a pager operable for receiving the forwarded theft alert message;

means for communicating a verified theft alert message to the central station in response to the forwarded theft message; and

a vehicle location system in communication with the central station and activated from the central station upon receipt of the verified theft alarm.

11. The vehicle theft monitoring and location system of claim 10 wherein the means for communicating and the pager are part of a two-way pager.

12. The vehicle theft monitoring and location system of claim 10 wherein the means for communicating is a telephone.

13. The vehicle theft monitoring and location system of claim 10, wherein the vehicle location system comprises:

a plurality of a base station receiver arrays each having an array of irregularly spaced dipole antennas operable for receiving the theft alert message and each capable of determining a direction of origin of the theft alert message;

the central station being connected to the plurality of base station receiver arrays, and operable for triangulating each of the direction of origin to determine the location of the vehicle.

14. The vehicle theft monitoring and location system of claim 13, wherein a reference station operates periodically to transmit a reference signal of known origin and location to calibrate the base station receiver arrays and the central station.

15. The vehicle theft monitoring and location system of claim 13, wherein determining the direction of origin of the theft alert message is by carrier phase interferometric direction finding.

16. The vehicle theft monitoring and location system of claim 13, wherein determining the direction of origin of the theft alert message is by differential time of arrival.

17. The vehicle theft monitoring and location system of claim 13, wherein determining the direction of origin of the theft alert message is by differential ranging.

18. A method of monitoring a vehicle's condition, comprising the steps of:

detecting a status condition from within a vehicle;

transmitting the status condition to a central station;

retransmitting the status condition to a paging device;

determining whether the status condition merits a response and responding with a status response if merited;

communicating the status response to the central station; and

forwarding the status response from the central station to the vehicle.

19. A method of monitoring a vehicle's condition, comprising the steps of:

detecting a status condition from within a vehicle;

transmitting the status condition to a central station;

retransmitting the status condition to a paging device;

determining whether the status condition merits a response and responding with a status response if merited;

communicating the status response to the central station; and

calculating the location of the vehicle.

20. The method of monitoring a vehicle's condition according to claim 19, wherein the step of calculating the location of the vehicle further includes performing interferometric direction finding and triangulation to determine the location.

21. A method of detecting vehicle alarms and discerning false alarms, comprising the steps of:

detecting an alarm condition on a vehicle;

transmitting an alarm condition message to a central station;

retransmitting the alarm condition message to a remote two-way paging device;

selecting, at the two-way paging device, whether the alarm condition is false or true to produce an alarm condition selection;

transmitting the alarm condition selection from the two-way paging device;

receiving the alarm condition selection at the central station; and

calculating the location of the vehicle if the alarm condition is true.

22. The method of detecting vehicle alarms according to claim 21, wherein the step of calculating the location of the vehicle further includes the step of performing interferometric direction finding and triangulation to determine the location.

23. The method of detecting vehicle alarms according to claim 22, wherein the step of calculating the location of the vehicle further includes the steps of:

receiving at a plurality of base stations the alarm condition message on a plurality of irregularly spaced antennas at each base station;

calculating the observed angle of arrival of the alarm condition message at each base station by comparing the phase difference of a radio frequency carrier signal of the alarm condition message between pairs of the plurality of irregularly spaced antennas;

communicating the observed angle of arrival at each base station to the central station; and

triangulating the observed angle of arrival from each base station to determine the vehicle location.

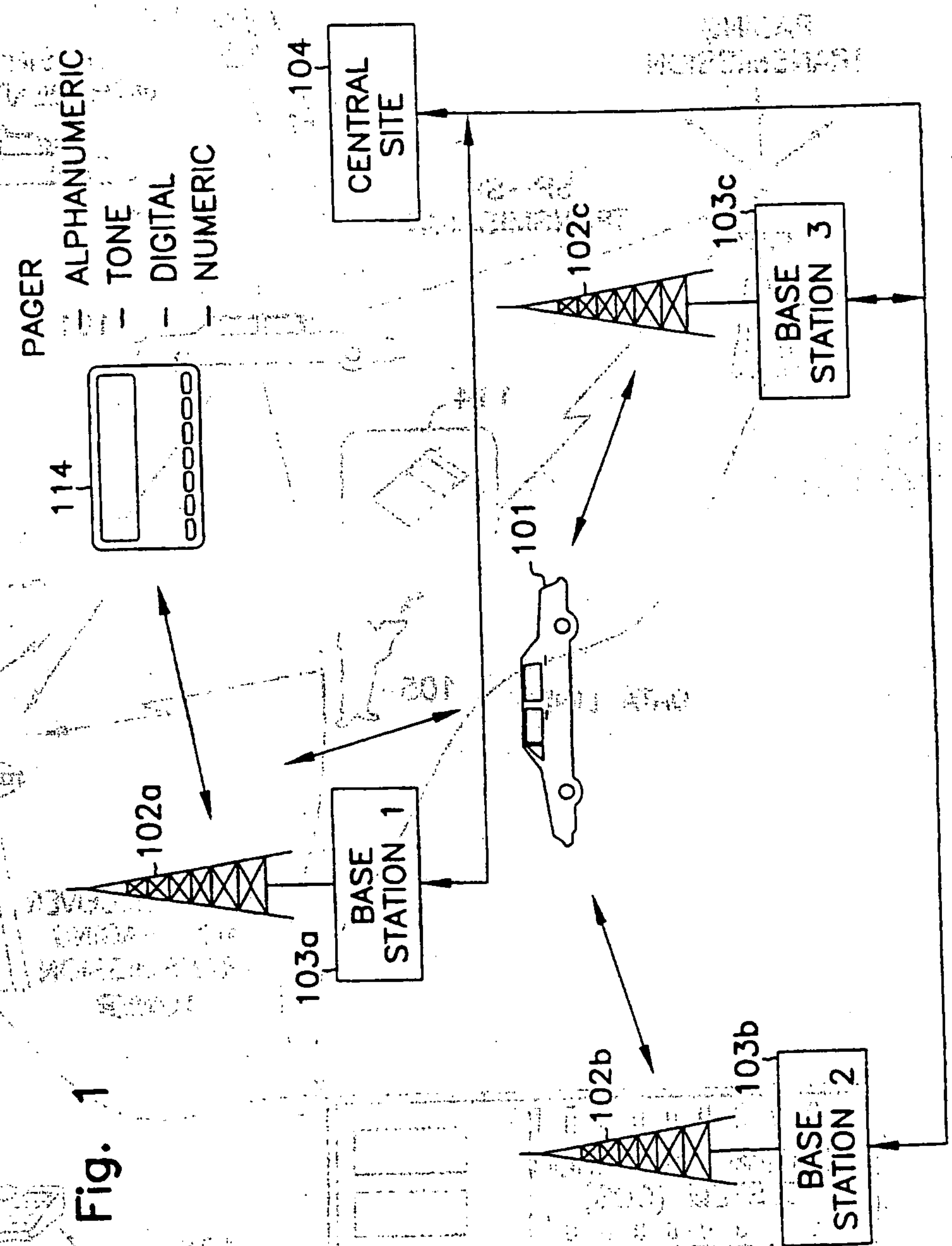

PAGER
ALPHANUMERIC
TONE
DIGITAL
NUMERIC
114
104
CENTRAL SITE
102c
103c
BASE STATION 3
101
102a
BASE STATION 1
103a
102b
103b
BASE STATION 2

Fig. 1

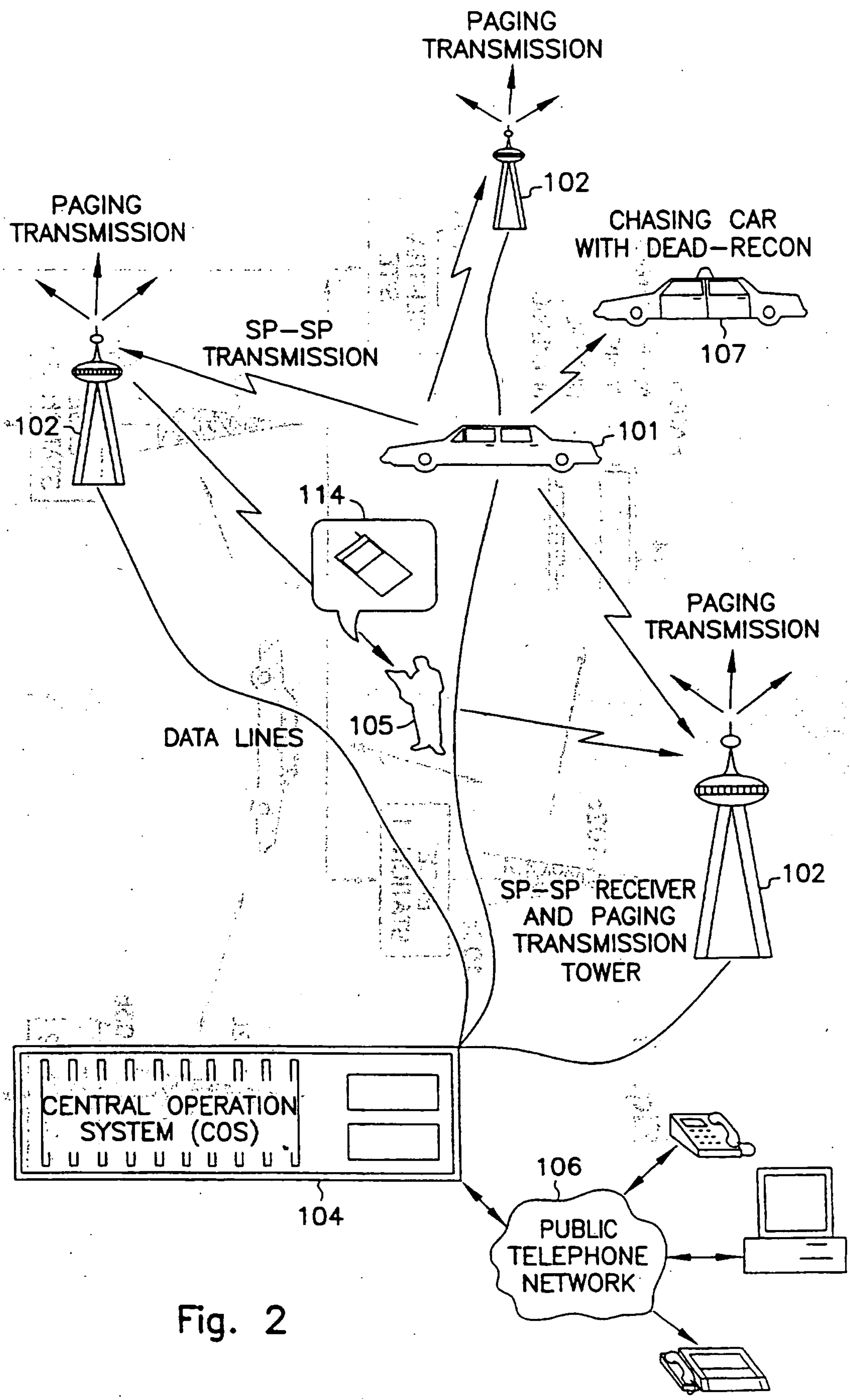

PAGING
TRANSMISSION
102
CHASING CAR
WITH DEAD-RECON
107
PAGING
TRANSMISSION
SP-SP
TRANSMISSION
102
101
114
PAGING
TRANSMISSION
105
DATA LINES
SP-SP RECEIVER
AND PAGING
TRANSMISSION
TOWER
102
CENTRAL OPERATION
SYSTEM (COS)
104
106
PUBLIC
TELEPHONE
NETWORK

Fig. 2

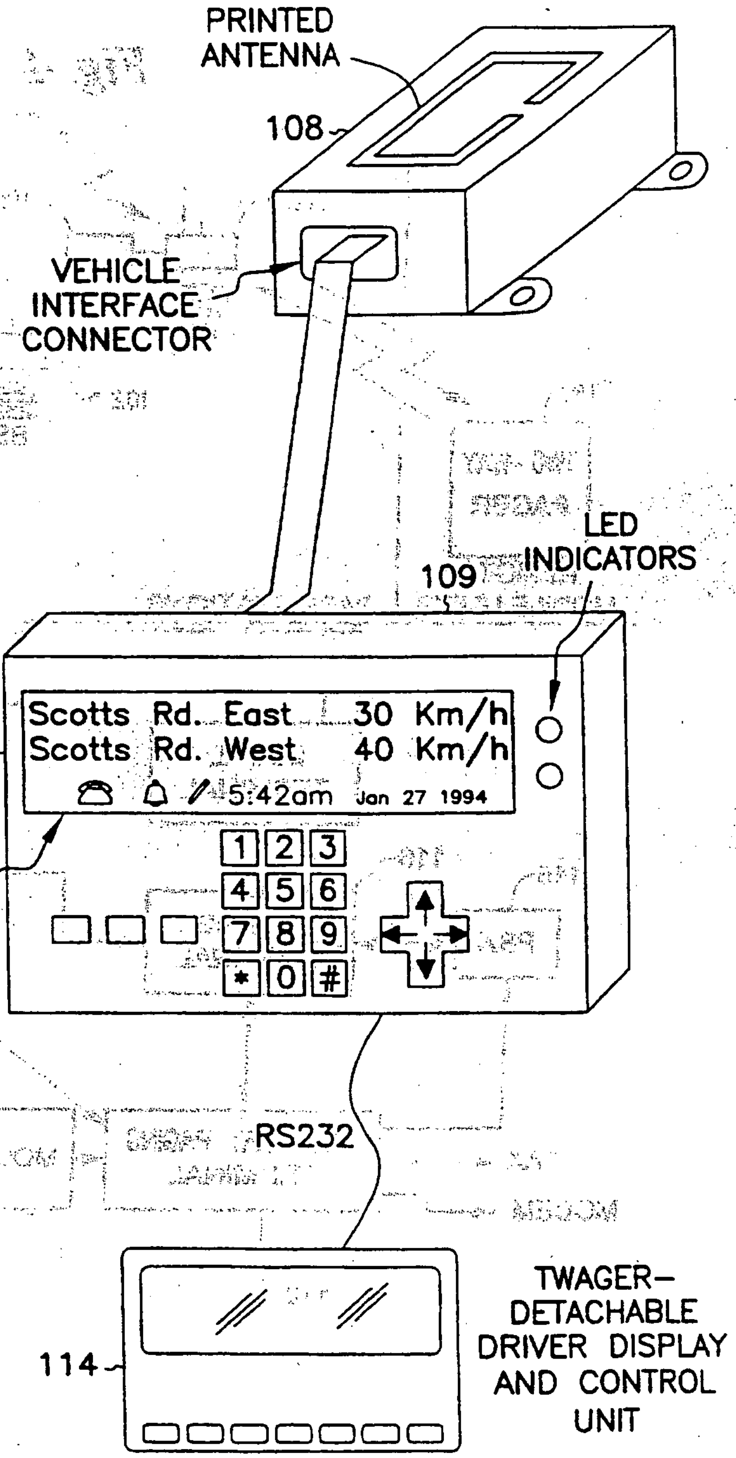
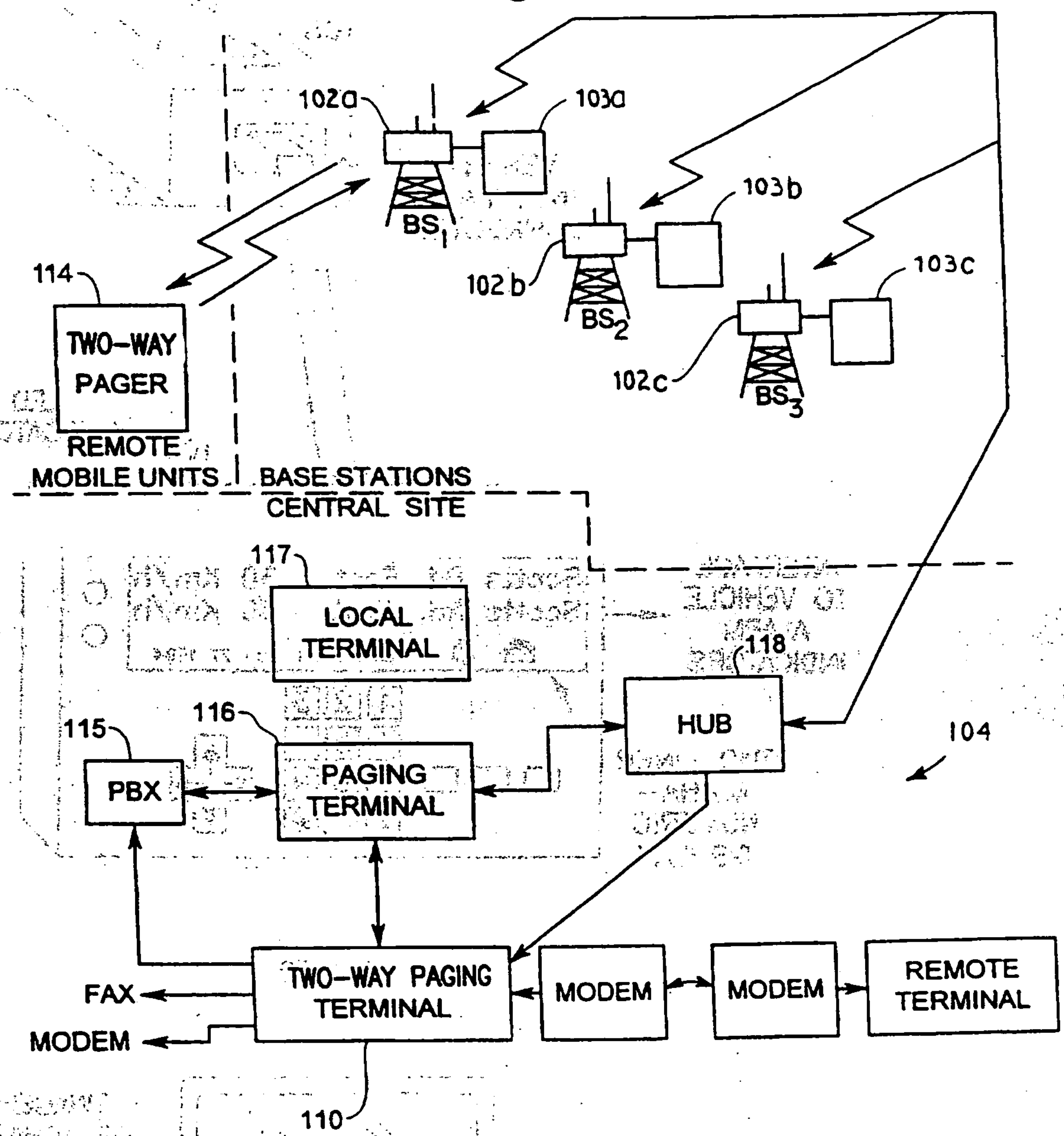

PRINTED ANTENNA
108
VEHICLE INTERFACE CONNECTOR
109
LED INDICATORS
INTERFACE TO VEHICLE ALARM INDICATORS
Scotts Rd. East 30 Km/h
Scotts Rd. West 40 Km/h
5:42am Jan 27 1994
1 2 3
4 5 6
7 8 9
* 0 #
TWO LINER ALPHA-NUMERIC DISPLAY
RS232
114
TWAGER-DETACHABLE DRIVER DISPLAY AND CONTROL UNIT

Fig. 3

Fig. 4


102a
103a
BS1
103b
102b
BS2
103c
102c
BS3
114
TWO-WAY PAGER
REMOTE MOBILE UNITS
BASE STATIONS
CENTRAL SITE
117
LOCAL TERMINAL
118
HUB
104
115
PBX
116
PAGING TERMINAL
TWO-WAY PAGING TERMINAL
MODEM
MODEM
REMOTE TERMINAL
FAX
MODEM
110

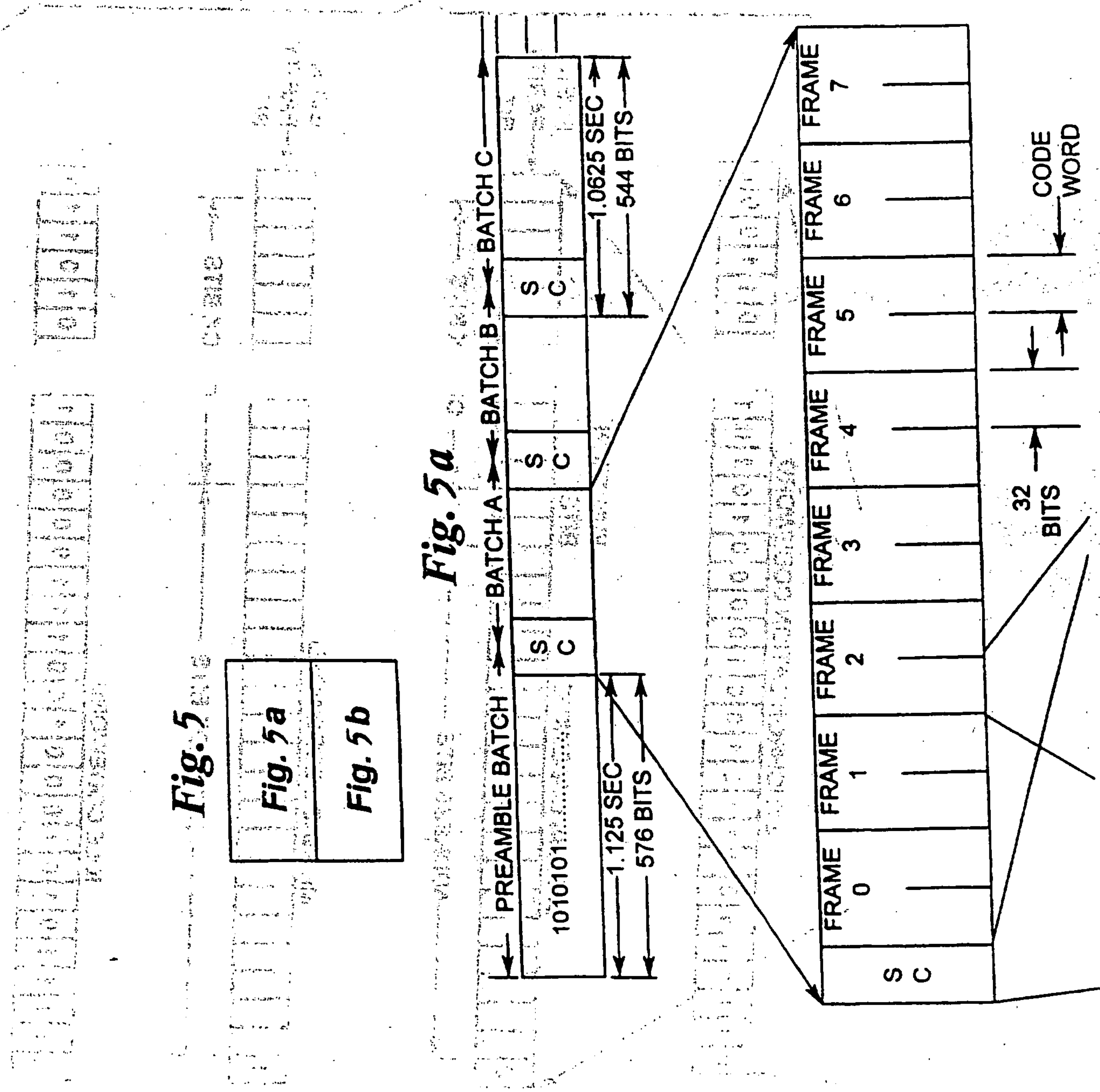
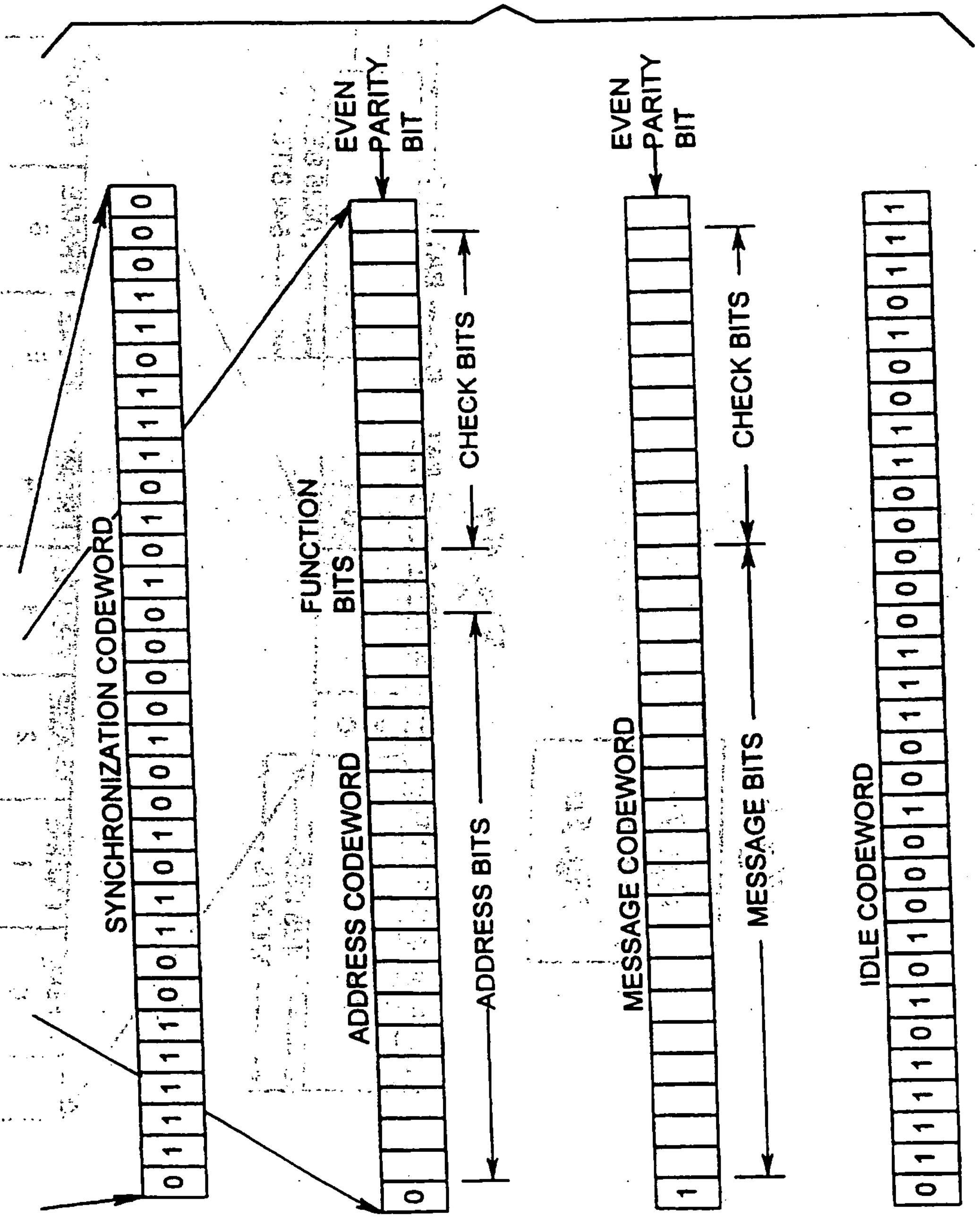


Fig. 5a
Fig. 5b
PREAMBLE BATCH
BATCH A
BATCH B
BATCH C
1010101
S C
S C
S C
1.125 SEC
576 BITS
1.0625 SEC
544 BITS
S C
FRAME 0
FRAME 1
FRAME 2
FRAME 3
FRAME 4
FRAME 5
FRAME 6
FRAME 7
32 BITS
CODE WORD

Fig. 5

Fig. 5a

Fig. 5b


SYNCHRONIZATION CODEWORD
ADDRESS CODEWORD
FUNCTION BITS
EVEN PARITY BIT
CHECK BITS
ADDRESS BITS
MESSAGE CODEWORD
EVEN PARITY BIT
CHECK BITS
MESSAGE BITS
IDLE CODEWORD

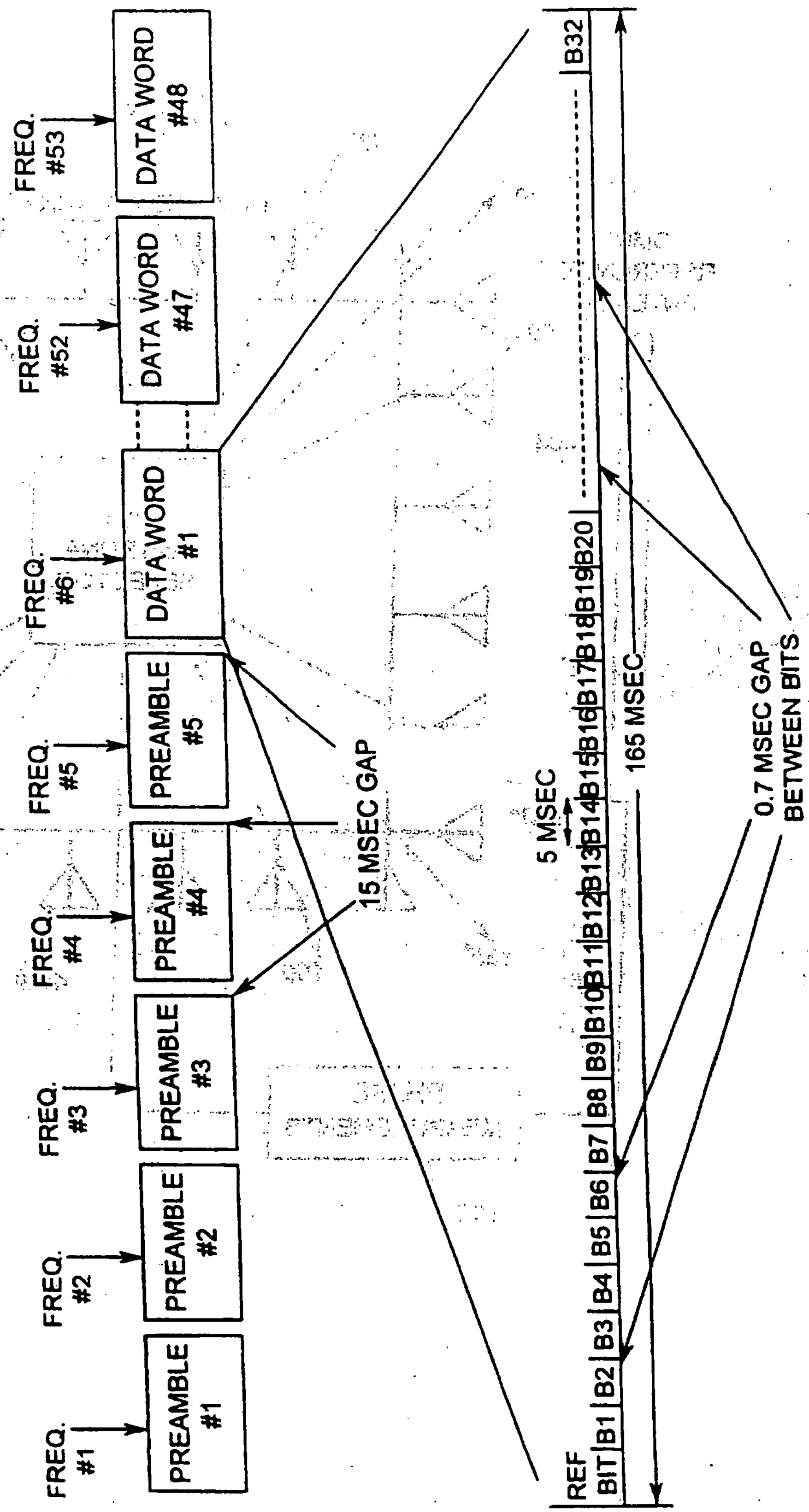

FREQ. #1
PREAMBLE #1
FREQ. #2
PREAMBLE #2
FREQ. #3
PREAMBLE #3
FREQ. #4
PREAMBLE #4
FREQ. #5
PREAMBLE #5
FREQ. #6
DATA WORD #1
FREQ. #52
DATA WORD #47
FREQ. #53
DATA WORD #48
15 MSEC GAP
REF BIT
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
B16
B17
B18
B19
B20
B32
5 MSEC
165 MSEC
0.7 MSEC GAP BETWEEN BITS

Fig. 6

Fig.7

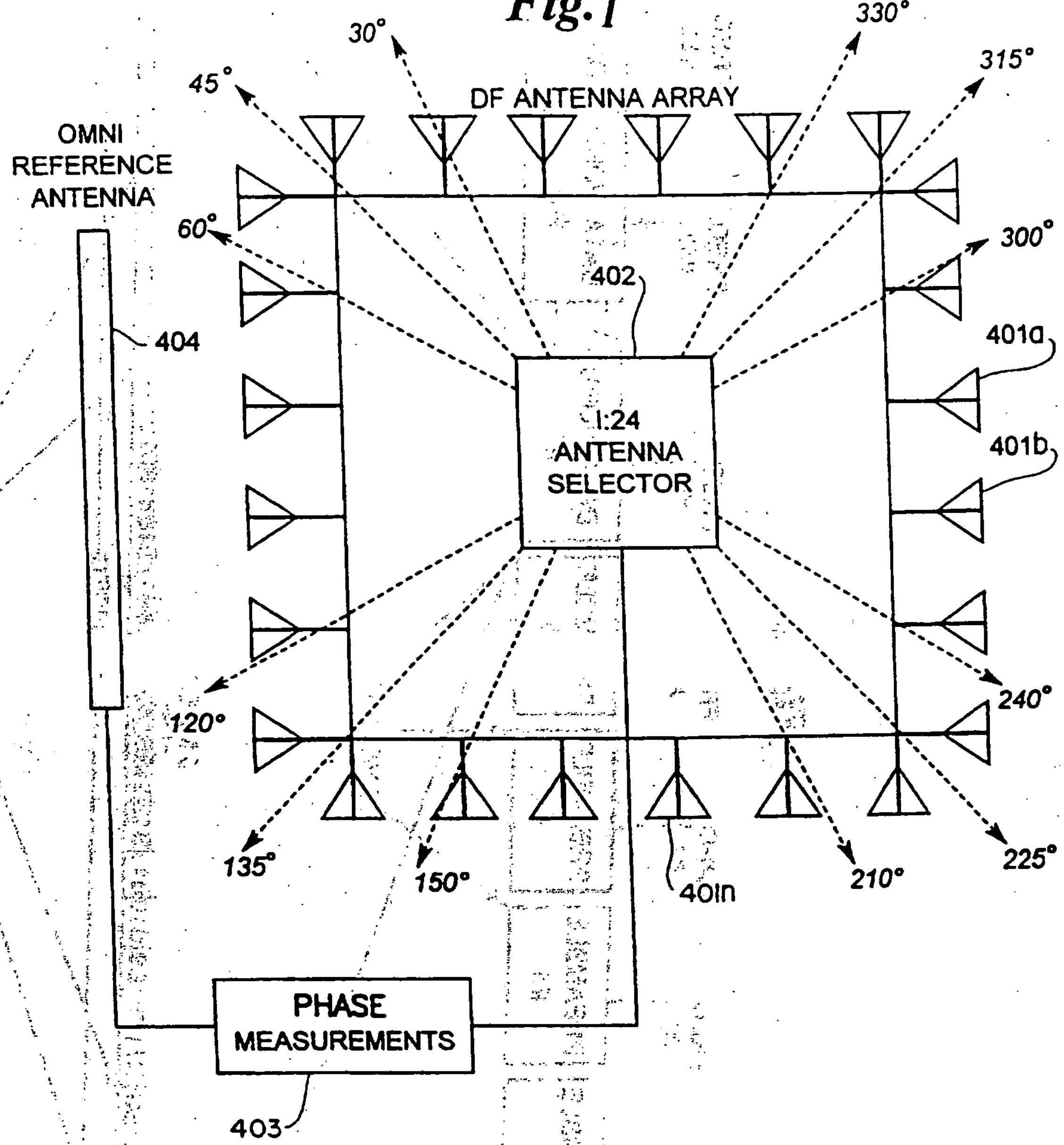

30°
330°
45°
315°
DF ANTENNA ARRAY
OMNI
REFERENCE
ANTENNA
60°
300°
402
404
401a
1:24
ANTENNA
SELECTOR
401b
120°
240°
135°
150°
210°
225°
401n
PHASE
MEASUREMENTS
403

Fig. 8

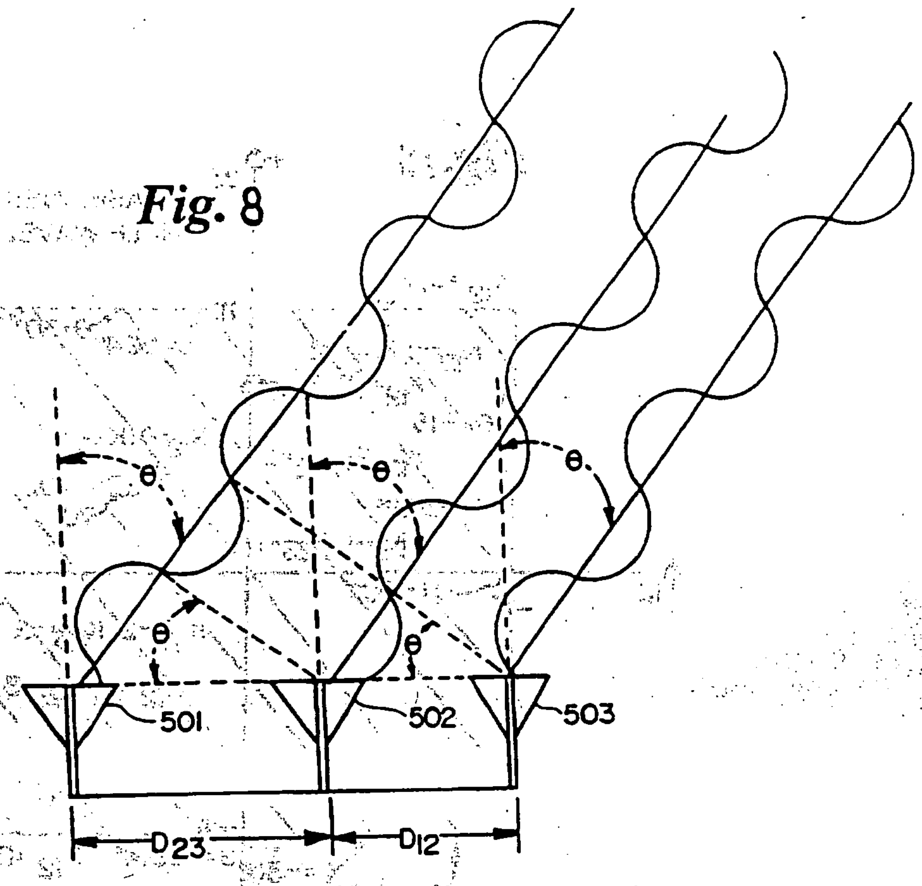

θ
θ
θ
θ
θ
501
502
503
D_{23}
D_{12}

Fig. 9

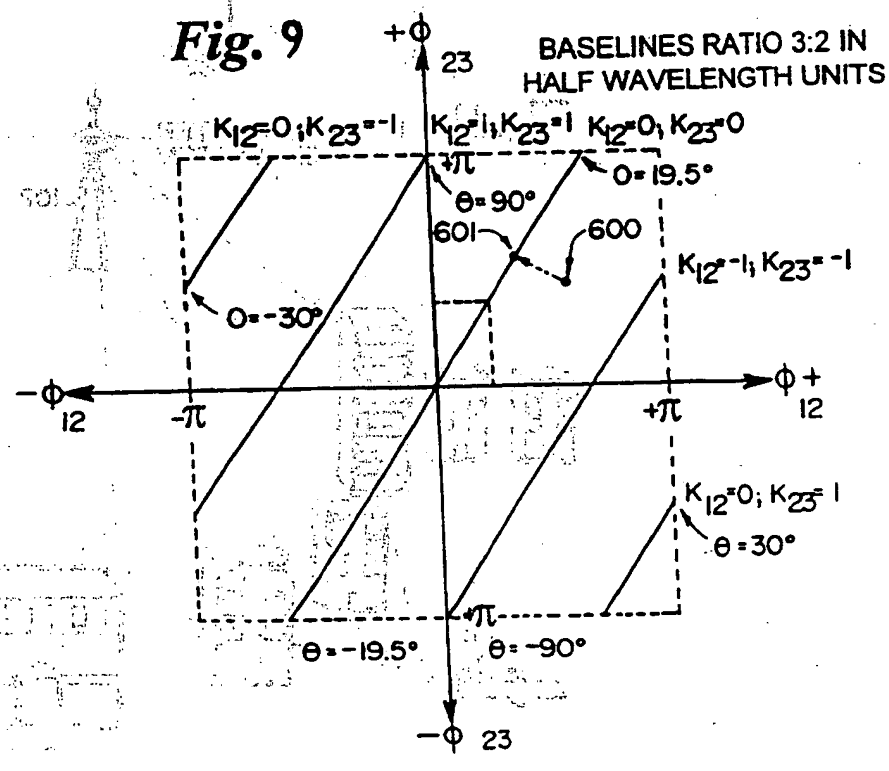

$+\Phi_{23}$
BASELINES RATIO 3:2 IN
HALF WAVELENGTH UNITS
$K_{12}=0; K_{23}=-1$
$K_{12}=1; K_{23}=1$
$K_{12}=0; K_{23}=0$
$+\pi$
$\theta=19.5°$
$\theta=90°$
601
600
$K_{12}=-1; K_{23}=-1$
$\theta=-30°$
$-\Phi_{12}$
$-\pi$
$+\pi$
$\Phi_{12}+$
$K_{12}=0; K_{23}=1$
$\theta=30°$
$+\pi$
$\theta=-19.5°$
$\theta=-90°$
$-\Phi_{23}$

Fig. 10

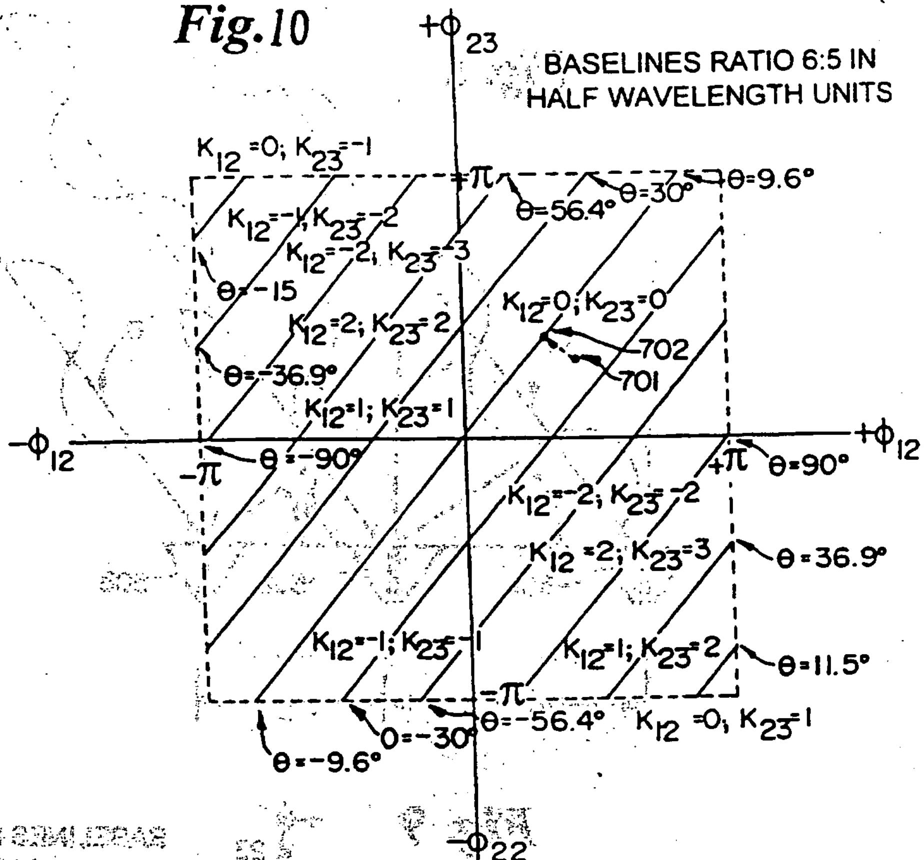

$+\phi_{23}$
BASELINES RATIO 6:5 IN HALF WAVELENGTH UNITS
$K_{12}=0; K_{23}=-1$
$+\pi$
$\theta=9.6°$
$\theta=30°$
$\theta=56.4°$
$K_{12}=-1; K_{23}=-2$
$K_{12}=-2; K_{23}=-3$
$\theta=-15$
$K_{12}=0; K_{23}=0$
$K_{12}=2; K_{23}=2$
702
$\theta=-36.9°$
701
$K_{12}=1; K_{23}=1$
$-\phi_{12}$
$+\phi_{12}$
$-\pi$
$\theta=-90°$
$+\pi$
$\theta=90°$
$K_{12}=-2; K_{23}=-2$
$K_{12}=2; K_{23}=3$
$\theta=36.9°$
$K_{12}=-1; K_{23}=-1$
$K_{12}=1; K_{23}=2$
$\theta=11.5°$
$-\pi$
$\theta=-56.4°$
$K_{12}=0; K_{23}=1$
$\theta=-30°$
$\theta=-9.6°$
$-\phi_{22}$

Fig. 11

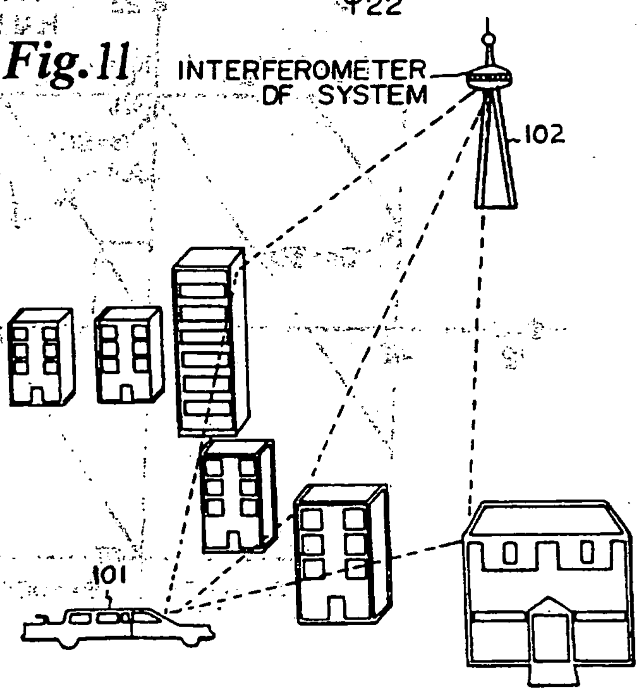

INTERFEROMETER DF SYSTEM
102
101

Fig. 12

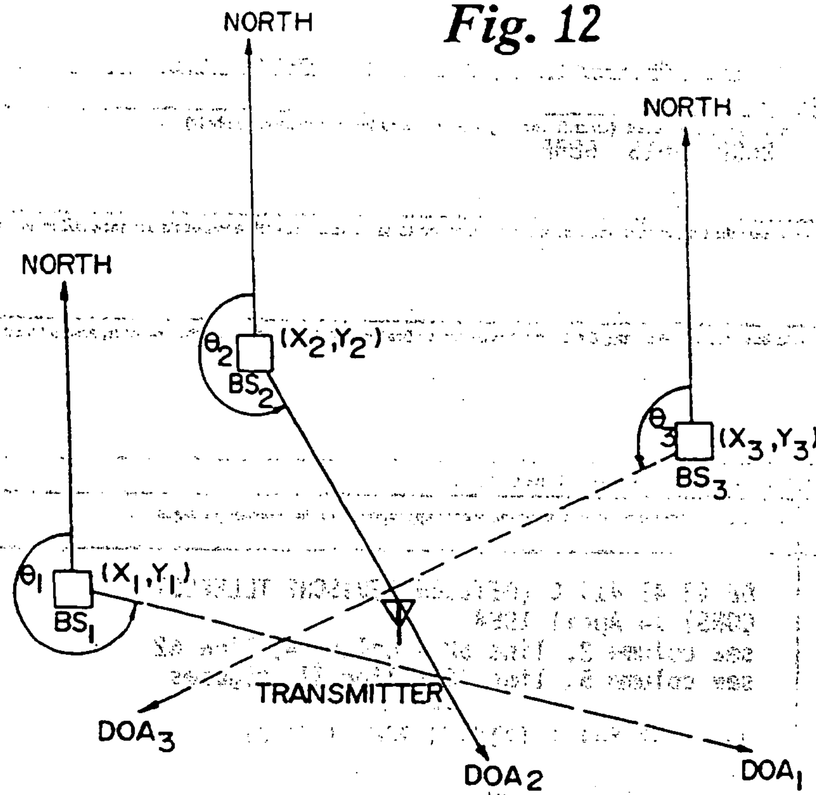
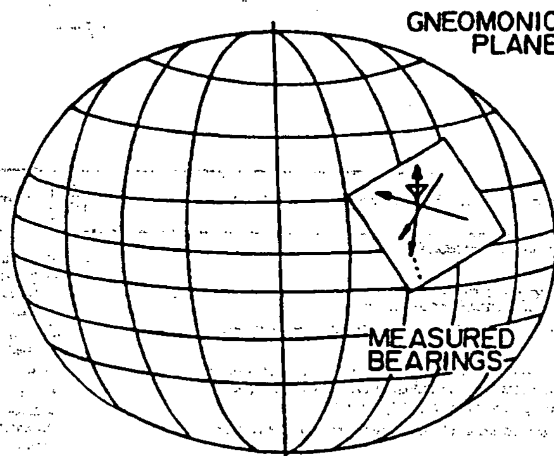

NORTH
NORTH
NORTH
θ_2
(X_2,Y_2)
BS_2
θ_3
(X_3,Y_3)
BS_3
θ_1
(X_1,Y_1)
BS_1
TRANSMITTER
DOA_3
DOA_2
DOA_1

Fig. 13


GNEOMONIC PLANE
MEASURED BEARINGS

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 97/00311

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 B60R25/10 G01S5/04 G08B25/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B60R G01S G08B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	DE 42 43 415 C (DETECON DEUTSCHE TELEPOST CONS) 14 April 1994 see column 2, line 52 - column 4, line 62 see column 5, line 10 - line 17; figures ---	1,2,4 3,5-7,18
X Y	US 5 247 564 A (ZICKER ROBERT G) 21 September 1993 see column 5, line 7 - column 6, line 25 ---	1,2,4, 10,19,21 11-15, 20,22,23
Y	GB 2 285 704 A (FLOUNDERS MICHAEL ;LAMBOURNE ROGER (GB)) 19 July 1995 see page 1, line 25 - page 3, line 15; figures ---	3,11,12, 18

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
7 July 1997	11.07.97
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Authorized officer Areal Calama, A-A

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INTERNATIONAL SEARCH REPORT

Inte... ...nal Application No
PCT/IB 97/00311

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 95 14936 A (NEXUS 1994 LIMITED) 1 June 1995 cited in the application see page 5, line 17 - page 8, line 5; figures & US 5 592 180 A ---	5,6, 13-15, 20,22,23
Y	WO 95 14935 A (NEXUS 1994 LIMITED) 1 June 1995 cited in the application see abstract; figures & US 5 583 517 A ---	7
A	GB 2 218 835 A (TRACKMOBILE INC) 22 November 1989 see page 22, line 7 - page 24, line 10; figures ---	1,10,16
A	US 3 703 714 A (ANDREWS MAURICE) 21 November 1972 see column 3, line 26 - line 62; figures -----	1,10

1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IB 97/00311

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 4243415 C	14-04-94	AU 5622494 A	04-07-94
		WO 9413515 A	23-06-94
US 5247564 A	21-09-93	NONE	
GB 2285704 A	19-07-95	NONE	
WO 9514936 A	01-06-95	US 5430759 A	04-07-95
		US 5592180 A	07-01-97
		AU 8113994 A	13-06-95
		AU 8114094 A	13-06-95
		AU 8114194 A	13-06-95
		EP 0730808 A	11-09-96
		WO 9515064 A	01-06-95
		WO 9514935 A	01-06-95
		US 5583517 A	10-12-96
		US 5546422 A	13-08-96
		US 5499266 A	12-03-96
		US 5519718 A	21-05-96
		US 5596330 A	21-01-97
WO 9514935 A	01-06-95	US 5430759 A	04-07-95
		US 5583517 A	10-12-96
		AU 8113994 A	13-06-95
		AU 8114094 A	13-06-95
		AU 8114194 A	13-06-95
		EP 0730808 A	11-09-96
		WO 9515064 A	01-06-95
		WO 9514936 A	01-06-95
		US 5592180 A	07-01-97
		US 5546422 A	13-08-96
		US 5499266 A	12-03-96
		US 5519718 A	21-05-96
		US 5596330 A	21-01-97
GB 2218835 A	22-11-89	US 4891650 A	02-01-90
		US 5055851 A	08-10-91
US 3703714 A	21-11-72	NONE	